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Research article

Global epidemiological trends in the incidence and deaths of acute respiratory infections from 1990 to 2021

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ABSTRACT

The aim of this study was to investigate the global epidemiological trends in the incidence and deaths of acute respiratory infections (ARIs), encompassing both upper respiratory infections (URIs) and lower respiratory infections (LRIs), from 1990 to 2021. Using data from the Global Burden of Disease study 2021 (GBD 2021), we utilized the average annual percentage change (AAPC) to examine the trends in the age-standardized incidence rate and deaths rate (ASIR and ASDRs) of URIs and LRIs. In 2021, the global ASIR of URIs and LRIs were 166,770.73 (95 % UI: 148,098.16–189,487.93) per 100,000 and 4283.61 (95 % UI: 4057.03–4524.89) per 100,000, respectively. The highest ASIR of URIs occurred in high-sociodemographic index (SDI) regions (232744.64, 95 % UI: 206887.07–261694.81) per 100,000, whereas LRIs occurred in low-SDI regions (9261.1, 95 % UI: 8741.61–9820.86) per 100,000. In 2021, the global ASDRs of URIs and LRIs were 0.28 (95 % UI: 0.09–0.61) per 100,000 and 28.67 (95 % UI: 25.92–31.07) per 100,000, respectively. The highest ASDRs of both URIs and LRIs were observed in low-SDI regions, with 1.1 (95 % UI: 0.08–2.78) per 100,000 and 70.68 (95 % UI: 62.56–78.62) per 100,000, respectively. From 1990 to 2021, the global ASIR for URIs and LRIs decreased, with AAPCs of −0.17 % (95 % CI: 0.17 % to −0.16 %) and −1.28 % (95 % CI: −1.37 % to −1.22 %), respectively. The global ASDRs also decreased (−3.39 % for URIs; −2.46 % for LRIs). However, during the COVID-19 pandemic, the ASIR of URIs increased in many countries, especially in high-SDI regions (rate difference before and during the COVID-19 pandemic in ASIR was 2210.19 per

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100,000.) and low-SDI regions (rate difference in ASIR: 111.26 per 100,000). The global incidence and deaths related to ARIs have decreased over the past 32 years. However, it remains a significant public health concern, particularly due to the notable incidence of URIs in high SDI regions and the deaths associated with both URIs and LRIs in low SDI regions. Furthermore, an increase in the incidence of URIs was observed in both high- and low-SDI regions during the COVID-19 pandemic, highlighting the need for increased attention.

1. Introduction

Acute respiratory infections (ARIs), including upper respiratory infections (URIs) and lower respiratory infections (LRIs), are characterized by symptoms such as cough, fever, nasal congestion, and, in severe cases, respiratory failure. These infections remain a public health priority because of their potential to cause substantial death and morbidity worldwide [1,2]. Annually, there is a significant burden of endemic respiratory diseases, accounting for approximately 4 % of global disability-adjusted life-years (DALYs) and resulting in 2.5 million deaths in 2019 due to ARIs [2]. A review by Riffat Naz et al. on the burden of ARIs in Pakistan revealed that in South Asia, 48 out of every 1000 children succumb to ARIs before the age of five. Specifically, in Pakistan, respiratory infections contribute to 20 %–30 % of all child deaths [3]. A study on the national burden of ARIs in Ecuador revealed that between 2011 and 2015, 14.84 million cases of ARIs were reported, resulting in 17,757 deaths. The average annual productivity loss due to ARIs is approximately 152 million USD (±19.6), with approximately 99 % of this burden attributed to premature death in the population under 5 years old and over 60 years old [4]. The disease burden related to ARIs in high-income regions also cannot be underestimated. In the United States, approximately 12 % of total deaths in 2020 were due to ARIs, making it the fourth leading cause of death across all age groups [5,6].

Several studies have reported the global burden associated with URIs and LRIs from 1990 to 2019 [7–10]. However, there is still a lack of systematic research on how the burden of URIs and LRIs has changed during the Coronavirus Disease 2019 (COVID-19) pandemic. In this study, our aim was to explore epidemiological trends in age-standardized incidence and deaths rates (ASIR and ASDRs) by sex and age at the global and regional levels from 1990 to 2021. Additionally, we systematically compared the incidences of URIs and LRIs before and during the COVID-19 pandemic, thereby providing comprehensive and up-to-date information on the global dynamics of ARIs.

2. Methods

2.1. Data sources

We obtained data on both the incidence and deaths rates for URIs and LRIs from 1990 to 2021 from the Global Burden of Disease study 2021 (GBD 2021). (https://vizhub.healthdata.org/gbd-results/). The GBD 2021 study provides a comprehensive and current estimation of the epidemiology of diseases and injuries across different sexes and age groups, covering 204 countries and territories and 21 GBD regions from 1990 to 2021. The GBD database utilizes the Bayesian meta-regression tool (DisMod-MR) to estimate the impact of various diseases and injuries on health by integrating data from diverse sources, including disease registries, vital registration systems, health care facilities, and surveys [1]. In GBD 2021, LRIs, including pneumonia, bronchiolitis, respiratory syncytial virus, and influenza-like illness, affect the lungs, presenting symptoms such as difficulty breathing and a rapid respiratory rate [11], and URIs encompass a range of conditions, such as cough, acute nasopharyngitis, sinusitis, pharyngitis, tonsillitis, laryngitis, tracheitis, epiglottitis, rhinitis, rhinosinusitis, rhinopharyngitis, and supraglottitis. These conditions typically present with symptoms such as a runny nose and sore throat [12]. We utilized the average rates of URIs and LRIs from 2018 to 2019 to signify the burden before the COVID-19 pandemic, and the average rates from 2020 to 2021 to represent the burden during the COVID-19 pandemic.

3. Statistical analysis

3.1. Joinpoint regression model

We employed a join-point regression model to assess the temporal trends of the ASIR and ASDRs of ARIs across different age groups, SDI ranks, and various GBD regions from 1990 to 2021. We calculated the average annual percentage changes (AAPCs) with 95 % confidence intervals (CIs). If the 95 % CI for AAPC does not include 0, it indicated a significant increasing or decreasing trend in the rates over time; otherwise, they were considered stable [13]. The rate differences between the average rates of 2020–2021 and those of 2018–2019 represents the variance in the incidence and deaths rates of URIs and LRIs before and during COVID-19.

We utilized Microsoft Excel 2016 to extract, sort, and clean the data. For statistical analysis, we employed Join-point (version 4.8.0.1) and R (version 4.2.2).

4. Results

4.1. Global and regional incidence and trends of ARIs from 1990 to 2021

In 2021, the global ASIR for URIs was 166,770.73/100,000 (95 % UI: 148,098.16/100,000–189,487.93/100,000). Regionally, countries in high-income North America, high-income Asia Pacific, and Tropical Latin America presented relatively high ASIRs (Table 1 and Fig. 1A-B-C). The global ASIR for LRIs was 4283.61/100,000 (95 % UI: 4057.03/100,000–4524.89/100,000), with the most severe impacts observed in South Asia, southern sub-Saharan Africa, and western sub-Saharan Africa (Table 2 and Fig. 2A and B-C). From 1990 to 2021, the global ASIRs for URIs and LRIs showed decreasing trends, with AAPCs of −0.17 % (95 % CI: 0.17 % to −0.16 %) and −1.28 % (95 % CI: 1.37 % to −1.22 %), respectively (Tables 1 and 2 and Fig. 1D and 2D).

4.2. SDI- and age-specific incidence rates and trends of ARIs from 1990 to 2021

In 2021, the high-SDI region presented the highest ASIR for URIs (232744.64/100,000, 95 % UI: 206887.07/100,000–261694.81/100,000). The highest incidence was observed among children under 5 years of age (302,140.68/100,000, 95 % UI: 237,648.68/100,000–366,477.5/100,000) and the lowest among those aged 70 and above (102,086.17/100,000, 95 % UI: 80,987.06/100,000–126,832.38/100,000). The incidence rate among children under 5 years of age has shown an increasing trend in recent years, particularly in high–middle-SDI regions (AAPC = 0.05 %, 95 % CI: 0.04 %–0.06 %) (Fig. 3A-F and Supplementary Table 1).

In 2021, the low-SDI region presented the highest ASIR for LRIs (9261.1/100,000, 95 % UI: 8741.61/100,000–9820.86/100,000). It was highest among individuals aged 70 and above (18,897.67/100,000, 95 % UI: 17,055.2/100,000–21,025.21/100,000) and lowest among adults aged 15–49 years (2249.6/100,000, 95 % UI: 2046.52/100,000–2458.86/100,000) (Fig. 4A−4 F and Supplementary Table 2).

4.3. Global and regional deaths and trends in ARIs from 1990 to 2021

In 2021, the global ASDRs for URIs was 0.28/100,000 (95 % UI: 0.09/100,000–0.61/100,000). Regionally, countries in Eastern Sub-Saharan Africa, Central Sub-Saharan Africa and Western Sub-Saharan Africa presented higher ASDRs (Table 1 and Fig. 1E–G). For LRIs, the ASDR was 28.67/100,000 (95 % UI: 25.92/100,000–31.07/100,000), with the most severe cases observed in Central Sub-Saharan Africa, Western Sub-Saharan Africa and Southern Sub-Saharan Africa (Table 2 and Fig. 2E–G). From 1990 to 2021, the global ASDRs for URIs and LRIs showed decreasing trends, with AAPCs of −3.39 % (95 % CI: 3.42 % to −3.37 %) and −2.46 % (95 % CI: 2.54 % to −2.39 %), respectively (Tables 1 and 2 and Fig. 1H–2H).

4.4. SDI- and age-specific deaths and trends in the incidence of ARIs from 1990 to 2021

The low-SDI region presented the highest ASDRs for URIs (1.1/100,000, 95% UI: 0.08/100,000–2.78/100,000) and LRIs (70.68/100,000, 95 % UI: 62.56/100,000–78.62/100,000) in 2021. The death rate was notably higher among children under 5 years old (1.64/100,000 (95 % UI: 0.28/100,000–4.05/100,000) for URIs; 76.26/100,000 (95 % UI: 61.95/100,000–91.98/100,000) for LRIs) and among those aged 70 years and above (0.76/100,000 for URIs; 224.67/100,000 for LRIs). Decreasing trends in ASDRs were observed across all SDI regions. Globally, the death rate from ARIs has decreased across all age groups. However, for LRIs, in individuals aged 70 years and above, the decrease was relatively slow (AAPC = −0.87 %, −0.95 % to −0.8 %) (Fig. 3G–L and Fig. 4G–L).

4.5. Rate differences in the incidence and deaths of ARIs before and during the COVID-19 pandemic

Compared to the period before COVID-19, many countries have shown a slight increase in the ASIRs of URIs, particularly in high-SDI regions (rate difference in ASIR: 2210.19 per 100,000) and in low-SDI areas (rate difference in ASIR: 111.26 per 100,000) (Fig. 5A and 6A). However, the deaths of LRIs and URIs, as well as the incidence of LRIs, have significantly decreased (Fig. 5B–D and 6B-D).

4.6. Etiology and risk factors contributing to deaths rate of LRIs

For deaths related to LRIs globally and across various SDI levels, the highest proportion was attributed to *Staphylococcus aureus* and *Streptococcus pneumoniae*, accounting for 23.16 % and 19.43 %, respectively (Supplementary Fig. 1). Globally, the primary risk factor contributing to LRI-related deaths was particulate matter pollution (34.86 %) (Supplementary Fig. 2).

5. Discussion

Our study investigated global trends in the incidence and deaths of URIs and LRIs over the past 32 years. We found that ARIs continue to exert a substantial global burden, especially in regions with both high and low SDI regions, as well as among individuals under 5 and over 70 years of age. While the overall incidence and death rates have demonstrated a declining trend over the past 32 years, individuals over 70 years of age have shown only a marginal decrease in deaths, thus maintaining a high burden. Additionally, during the COVID-19 pandemic, an increase in the incidence of URIs was observed in both high- and low-SDI regions.

In our study, we observed that children under 5 years of age exhibited the highest incidence and death rates for URIs. This aligns

Table 1
The Age-standardized Incidence and Deaths rates of Upper Respiratory Infections in 1990, 2019 and 2021 with AAPCs over the 32 years.

	Incidence (/100,000)			AAPC (%, 95 % CI)	Death(/100,000)			AAPC (%, 95 % CI)
	1990	2019	2021		1990	2019	2021	
Global	175481.29 (156152.47–198878.54)	166593.47 (148049.67–188831.94)	166770.73 (148098.16–189487.93)	−0.17 (−0.17 to −0.16)*	0.81 (0.23–1.21)	0.29 (0.1–0.63)	0.28 (0.09–0.61)	−3.39 (−3.42 to −3.37)*
Sex								
Female	177646.04 (158006.53–200918.72)	168335.43 (149852.95–190953.52)	168612.56 (149878.86–191498.75)	−0.17 (−0.17 to −0.17)*	0.77 (0.21–1.22)	0.29 (0.07–0.73)	0.27 (0.07–0.7)	−3.31 (−3.35 to −3.28)*
Male	173360.63 (154231.09–196697.06)	164904.63 (146447.51–186779.54)	164979.11 (146441.39–187531.5)	−0.16 (−0.17 to −0.16)*	0.86 (0.24–1.28)	0.3 (0.1–0.63)	0.29 (0.09–0.61)	−3.49 (−3.51 to −3.47)*
Age group								
<5 years	319253.16 (253533.3–385614.32)	298635.69 (236246.09–359558.15)	302140.68 (237648.68–366477.5)	−0.18 (−0.19 to −0.17)*	3.15 (1.02–5.76)	1.74 (0.32–4.24)	1.64 (0.28–4.05)	−2.1 (−2.14 to −2.06)*
5–14 years	205938.05 (154386–268035.83)	195309.23 (145970.2–255585.67)	195419.2 (145824.07–256116.5)	−0.17 (−0.17 to −0.17)*	0.15 (0.03–0.28)	0.1 (0.01–0.24)	0.09 (0.01–0.22)	−1.51 (−1.54 to −1.48)*
15–49 years	157790.14 (131828.69–187203.2)	149145.62 (126123.47–175795.53)	148755.38 (125691.42–175491.92)	−0.19 (−0.2 to −0.19)*	0.1 (0.03–0.16)	0.05 (0.01–0.1)	0.05 (0.01–0.1)	−2.39 (−2.41 to −2.37)*
50–69 years	132415.59 (104885.93–164870.57)	126369.61 (100171.65–157953.63)	125987.84 (99756.69–157339.23)	−0.16 (−0.17 to −0.16)*	0.52 (0.14–0.78)	0.14 (0.06–0.26)	0.14 (0.06–0.26)	−4.22 (−4.24 to −4.19)*
70+ years	108582.05 (85560.29–136134.03)	101690.27 (80569.61–126700.92)	102086.17 (80987.06–126832.38)	−0.2 (−0.21 to −0.2)*	4.73 (1.2–6.77)	0.78 (0.46–1.3)	0.76 (0.44–1.3)	−5.75 (−5.8 to −5.7)*
SDI rank								
High SDI	244417.71 (216965.23–275014.71)	229397.18 (203419.44–258191.91)	232744.64 (206887.07–261694.81)	−0.16 (−0.17 to −0.15)*	0.17 (0.14–0.19)	0.03 (0.02–0.03)	0.02 (0.02–0.03)	−6.14 (−6.21 to −6.06)*
High-middle SDI	165828.51 (146841.12–188311.57)	164739.98 (146195.33–187143.37)	164685.58 (146019.1–187645.38)	−0.02 (−0.03 to −0.02)*	0.87 (0.29–1.25)	0.08 (0.06–0.17)	0.08 (0.06–0.17)	−7.54 (−7.61 to −7.47)*
Middle SDI	167801.31 (148789.98–190579.31)	165410.96 (146247.84–188803.89)	165394.25 (146461.07–188308.91)	−0.05 (−0.05 to −0.05)*	1.35 (0.31–1.99)	0.12 (0.09–0.22)	0.11 (0.08–0.2)	−7.73 (−7.8 to −7.66)*
Low-middle SDI	158350.75 (140751.46–179447.94)	153919.28 (136912.06–174508.16)	153830.74 (136960.57–175052.67)	−0.09 (−0.1 to −0.09)*	0.41 (0.08–0.78)	0.25 (0.07–0.46)	0.22 (0.06–0.42)	−1.94 (−1.98 to −1.9)*
Low SDI	149051.76 (132415.07–169143.98)	146645.48 (130414.15–166418.4)	146602.2 (130473.03–166277.37)	−0.05 (−0.06 to −0.05)*	1.61 (0.11–3.83)	1.18 (0.09–2.94)	1.1 (0.08–2.78)	−1.22 (−1.23 to −1.2)*
GDB regions								
Southeast Asia, east Asia, and Oceania								
Southeast Asia	204907.06 (181883.59–231235.91)	199258.64 (175813.39–226496.87)	199235.91 (175708.01–226569.61)	−0.08 (−0.09 to −0.08)*	0.08 (0.02–0.18)	0.03 (0.02–0.06)	0.03 (0.02–0.05)	−3.69 (−3.72 to −3.66)*
East Asia	138364.4 (121576.2–158499.94)	137589.02 (120797.36–157776.07)	137200.24 (120497.82–157136.25)	−0.03 (−0.04 to −0.02)*	3.01 (0.57–4.52)	0.16 (0.1–0.4)	0.15 (0.09–0.36)	−9.2 (−9.28 to −9.12)*
Oceania	214629.64 (189872.29–245734.48)	216020.72 (191310.57–243584.8)	216592.94 (191450.24–245184.51)	0.03 (0.03–0.03)*	0.04 (0–0.13)	0.02 (0–0.08)	0.02 (0–0.08)	−1.75 (−1.78 to −1.73)*
Sub-Saharan Africa								
Western Sub-Saharan Africa	143869.37 (127639.58–163520.93)	141573.42 (125804.32–161692.06)	141507.19 (125697.02–161196.19)	−0.05 (−0.06 to −0.05)*	1.92 (0.18–5.21)	1.34 (0.16–3.84)	1.26 (0.14–3.57)	−1.34 (−1.37 to −1.32)*
Central Sub-Saharan Africa	172263.31 (152175.7–195647.06)	167235.81 (147782.71–190531.03)	166923.37 (147522.63–188923.47)	−0.1 (−0.1 to −0.1)*	1.96 (0.18–4.96)	1.35 (0.1–4.77)	1.27 (0.09–4.6)	−1.39 (−1.41 to −1.36)*
Southern Sub-Saharan Africa	227220.86 (200202.21–257155.46)	220374.15 (195995.07–249271.49)	218125.61 (194201.07–246407.16)	−0.13 (−0.14 to −0.12)*	0.8 (0.41–1.58)	0.48 (0.3–0.71)	0.46 (0.28–0.67)	−1.72 (−1.77 to −1.67)*
Eastern Sub-Saharan Africa	164388.69 (145812.52–186258.77)	163806.06 (145841.15–185713.52)	163889.18 (145695.78–185497.29)	−0.01 (−0.01 to −0.01)*	2.48 (0.18–6.06)	1.67 (0.1–4.32)	1.58 (0.09–4.17)	−1.44 (−1.46 to −1.43)*

(*continued on next page*)

Table 1 (*continued*)

	Incidence (/100,000)			AAPC (%, 95 % CI)	Death(/100,000)			AAPC (%, 95 % CI)
	1990	2019	2021		1990	2019	2021	
South Asia	143714.54 (127187.63–163440.79)	137124.17 (121561.67–155980.35)	136983.62 (121538.6–156142.66)	−0.16 (−0.17 to −0.15)*	0.22 (0.01–0.45)	0.13 (0.02–0.26)	0.11 (0.02–0.23)	−2.29 (−2.35 to −2.23)*
Latin America and Caribbean								
Tropical Latin America	247639.85 (218688.87–280811.11)	242769.04 (214586.51–277180.39)	242554.24 (212927.78–276375.88)	−0.07 (−0.07 to −0.06)*	0.15 (0.14–0.16)	0.06 (0.06–0.07)	0.06 (0.05–0.06)	−3.09 (−3.18 to −2.99)*
Caribbean	183721.68 (163360.2–207629.13)	185955.84 (164941.51–210967.93)	186042.33 (164416.08–210791.28)	0.04 (0.03–0.04)*	0.16 (0.08–0.3)	0.08 (0.03–0.18)	0.08 (0.03–0.17)	−2.09 (−2.14 to −2.04)*
Andean Latin America	197571.62 (175306.43–225746.13)	196608.25 (172671.87–225390)	196745.97 (172869.07–224104.55)	−0.01 (−0.02 to −0.01)*	0.36 (0.17–0.68)	0.07 (0.04–0.1)	0.06 (0.04–0.09)	−5.71 (−5.8 to −5.64)*
Central Latin America	195831.72 (174236.49–221306.93)	194407.88 (171655.95–220828.71)	194563.33 (171403.28–221233.11)	−0.02 (−0.03 to −0.02)*	0.72 (0.66–0.78)	0.07 (0.06–0.08)	0.06 (0.05–0.08)	−7.66 (−7.75 to −7.57)*
North Africa and Middle East	165123.77 (146650.27–186469.93)	156718.75 (139381.13–177062.27)	157435.27 (139786.08–179332.86)	−0.15 (−0.16 to −0.15)*	0.15 (0.04–0.4)	0.07 (0.04–0.13)	0.06 (0.04–0.12)	−2.93 (−2.99 to −2.88)*
Central Europe, eastern Europe, and central Asia								
Central Europe	136076.4 (120309.51–155134.1)	135697.82 (120281.82–155017.63)	135709.61 (120162.97–154473.63)	−0.01 (−0.01 to −0.01)*	0.15 (0.12–0.17)	0.02 (0.02–0.03)	0.02 (0.02–0.03)	−5.89 (−5.98 to −5.8)*
Central Asia	104458.64 (92328.05–119543.31)	101159.86 (89733.01–115726.38)	100853.61 (89257.5–115001.65)	−0.11 (−0.11 to −0.11)*	0.74 (0.45–1.05)	0.36 (0.25–0.49)	0.33 (0.23–0.46)	−2.57 (−2.65 to −2.48)*
Eastern Europe	183839.22 (163202.87–209465.29)	183899.88 (163385.64–209021.7)	183955.19 (163129.1–209785)	0 (0–0)	0.47 (0.44–0.51)	0.1 (0.1–0.11)	0.1 (0.09–0.11)	−4.94 (−5.04 to −4.87)*
High-income regions								
High-income North America	332754.41 (297062.43–372909.19)	290186.92 (258745.96–325020.07)	297926.78 (265745.76–333144.65)	−0.36 (−0.38 to −0.35)*	0.07 (0.06–0.07)	0.02 (0.02–0.03)	0.02 (0.02–0.02)	−3.41 (−3.51 to −3.31)*
High-income Asia Pacific	248805.14 (219726.02–281883.78)	246289.97 (217866.81–277579.25)	247404.97 (219448.51–279609.93)	−0.02 (−0.02 to −0.02)*	0.49 (0.39–0.6)	0.02 (0.02–0.03)	0.02 (0.02–0.03)	−9.89 (−9.97 to −9.8)*
Australasia	238899.17 (209419.01–271686.46)	236930.44 (209058.8–266858.87)	237761.19 (209660.07–269978.57)	−0.02 (−0.02 to −0.01)*	0.07 (0.07–0.08)	0.03 (0.02–0.03)	0.02 (0.02–0.03)	−3.64 (−3.94 to −3.29)*
Western Europe	205253.85 (180813.51–232603.03)	203117.8 (178889.88–230018.12)	204141.01 (180594.83–231769.2)	−0.01 (−0.02 to −0.01)*	0.1 (0.1–0.11)	0.03 (0.02–0.03)	0.02 (0.02–0.03)	−4.74 (−4.84 to −4.66)*
Southern Latin America	236825.22 (209420.71–267209.98)	234565.49 (207841.97–264196.61)	235918.96 (208206.18–267176.12)	−0.01 (−0.01 to −0.01)*	0.06 (0.06–0.07)	0.02 (0.01–0.02)	0.01 (0.01–0.02)	−4.76 (−4.95 to −4.61)*

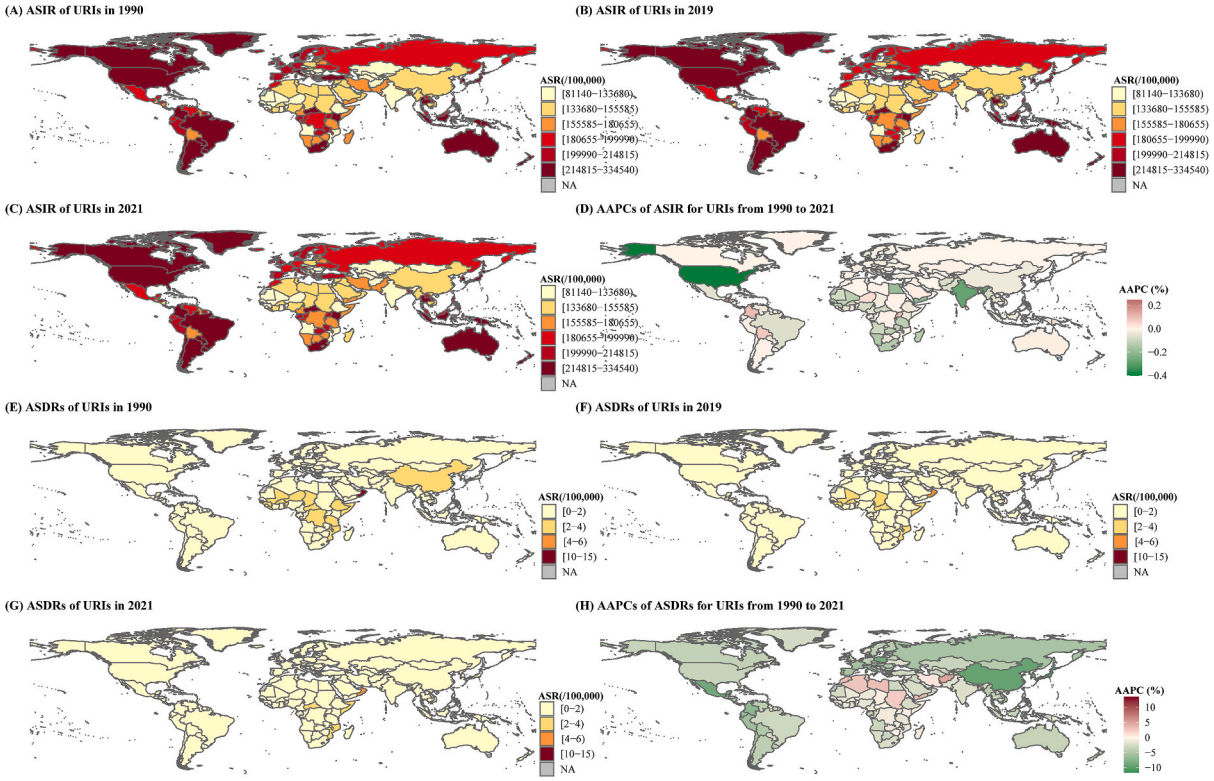

Fig. 1. Global Incidence and Deaths rates of Upper Respiratory Infections among 204 Countries and Territories. (A) ASIR in 1990; (B) ASIR in 2019; (C) ASIR in 2021; (D) AAPC in ASIR from 1990 to 2021; (E) ASDR in 1990; (F) ASDR in 2019; (G) ASDR in 2021; (H) AAPC in ASDR from 1990 to 2021.

with previous research [7]. Young children frequently engage with peers in settings such as daycare facilities and preschools, where their limited adherence to hygiene practices, including handwashing, increases the potential for URLs transmission [14]. Moreover, before the age of 5, infants and young children have not yet fully developed mature immune systems. Maternal antibodies provide protection for only approximately six months, leaving newborns and young children relatively susceptible to bacterial and viral infections, as well as at a higher risk of developing more severe complications and deaths [15]. Symptoms of LRIs are often more severe than those of URIs and are more prevalent among the elderly. Adults aged 70 years and older had the highest incidence and death rates for LRIs. Elderly individuals undergo irreversible declines in immune function and respiratory system function, alongside the presence of chronic diseases. This leads to the manifestation of more complex symptoms, a poorer prognosis, and a higher mortality rate among older adults [16,17].

Previous studies have indicated that the incidence and deaths of URIs and LRIs are higher in males than in females due to differences in immune response, as well as variations in behaviors such as smoking and alcohol consumption [18–20]. Females often exhibit a stronger immune system, and simultaneously, unhealthy behaviors such as smoking and alcohol consumption are relatively less prevalent among women than among males [18]. However, according to the data released in the GBD 2021, the incidence of URIs in females has surpassed that in males. This may be related to the greater willingness of women to seek medical care, while the efforts made by men to maintain an idealized image seem to affect their attention to health. As a result, men are less likely to seek medical attention when they have a cold, leading to a lower reported number of male patients receiving URIs [21,22]. Further researches are needed to elucidate the specific reasons behind this phenomenon.

The swift economic and social changes in high-SDI areas have led to a notable rise in population density, potentially aiding the transmission of respiratory pathogens [23]. This, coupled with a significant increase in ambient particulate matter pollution emissions, has been significantly linked to the incidence and deaths of URIs and LRIs [24]. The death rate of ARIs remains relatively high in low-SDI regions. Several factors, including low birth weight, child wasting, household air pollution from solid fuels, exposure to tobacco and inadequate health care resources, contribute to a higher death rate due to ARIs [23,25–27]. The substantial disease burden should be alleviated by shifting the focus toward achieving high-quality fundamental health care services [25,28]. It is also imperative to enhance educational initiatives concerning personal protective measures among individuals residing in countries with low SDI. Additionally, studies have shown that moderate levels of walking and running, as among the most effective means of stimulating exercise, can enhance immune system function and reduce inflammation in the body [29]. This, in turn, helps mitigate severe complications and the disease burden associated with respiratory infections.

Streptococcus pneumoniae is the primary pathogen responsible for the majority of LRIs-related deaths. As an opportunistic pathogen,

Table 2
The Age-standardized Incidence and Deaths rates of Lower Respiratory Infections in 1990, 2019 and 2021 with AAPCs over the 32 years.

	Incidence (/100,000)			AAPC (%, 95 % CI)	Death(/100,000)			AAPC (%, 95 % CI)
	1990	2019	2021		1990	2019	2021	
Global	6373.17 (5993.51–6746.04)	4744.93 (4497.06–5011.96)	4283.61 (4057.03–4524.89)	−1.28 (−1.37 to −1.22)*	61.81 (56.66–66.74)	34.69 (31.57–37.55)	28.67 (25.92–31.07)	−2.46 (−2.54 to −2.39)*
Sex								
Female	5790.87 (5458.63–6145.5)	4203.86 (3977.32–4447.52)	3861.73 (3647.21–4080.66)	−1.32 (−1.41 to −1.25)*	56.37 (50.55–61.63)	30.15 (26.49–32.9)	24.5 (21.24–27.1)	−2.69 (−2.78 to −2.61)*
Male	7115.52 (6694.46–7528.04)	5368.29 (5085.18–5671.87)	4754.15 (4510.74–5032.1)	−1.33 (−1.42 to −1.26)*	70.02 (64.82–75.26)	40.87 (37.67–44.18)	34.25 (31.42–37.05)	−2.29 (−2.36 to −2.24)*
Age group								
<5 years	16302.63 (14488.96–18341.73)	6639.04 (5903.76–7493.27)	5747.46 (5085.16–6537.07)	−3.34 (−3.43 to −3.27)*	313.74 (273.3–357.96)	102.21 (85.17–120.15)	76.26 (61.95–91.98)	−4.54 (−4.66 to −4.45)*
5–14 years	3893.01 (3169.07–4719.55)	2560.38 (2117.07–3062.54)	2369.25 (1954.01–2841.78)	−1.61 (−1.65 to −1.58)*	7.95 (6.68–8.92)	3.91 (3.42–4.39)	3.23 (2.79–3.65)	−2.88 (−2.96 to −2.79)*
15–49 years	2460.18 (2229.34–2703.7)	2415.02 (2197.9–2641.56)	2249.6 (2046.52–2458.86)	−0.34 (−0.44 to −0.27)*	5.19 (4.79–5.54)	4.46 (4.12–4.85)	4.05 (3.72–4.45)	−0.8 (−0.87 to −0.72)*
50–69 years	8325.67 (7540.44–9112.54)	6965.48 (6349.8–7581.74)	6366.32 (5801.95–6936.25)	−0.92 (−1.03 to −0.82)*	35.6 (32.82–38.16)	28.62 (26.28–30.74)	25.51 (23.27–27.57)	−1.05 (−1.11 to −1)*
70+ years	22654.92 (20326.72–25095.78)	21560.17 (19575.19–24087.39)	18897.67 (17055.2–21025.21)	−0.63 (−0.74 to −0.56)*	294.98 (268.2–318.8)	266.35 (233.61–287.73)	224.67 (197.66–244.15)	−0.87 (−0.95 to −0.8)*
SDI rank								
High SDI	1661.1 (1574.31–1765.25)	1109.78 (1054.09–1171.52)	891.11 (844.55–942.63)	−1.98 (−2 to −1.96)*	25.64 (23.19–26.89)	15.35 (13.39–16.42)	12.05 (10.44–12.92)	−2.38 (−2.53 to −2.25)*
High-middle SDI	3875.95 (3635.71–4122.19)	3126.69 (2933.63–3367.4)	2707.6 (2540.86–2896.77)	−1.17 (−1.22 to −1.14)*	29.43 (27.31–31.69)	16.53 (14.99–17.74)	13.79 (12.36–15.16)	−2.4 (−2.53 to −2.28)*
Middle SDI	6136.39 (5786.14–6472.47)	4142.67 (3905.37–4384.07)	3682.81 (3486.66–3914.42)	−1.67 (−1.76 to −1.6)*	58.73 (54.11–62.74)	29.99 (27.2–32.13)	25.43 (22.91–27.61)	−2.71 (−2.81 to −2.61)*
Low-middle SDI	12914.58 (12086.11–13665.23)	9015.28 (8518.72–9559.94)	8258.51 (7738.26–8773.55)	−1.45 (−1.56 to −1.37)*	81.98 (74.39–89.32)	51.9 (46.86–56.36)	43.12 (38.11–47.74)	−2.1 (−2.22 to −2.01)*
Low SDI	13580.08 (12769.84–14376.02)	10067.52 (9505.79–10662.96)	9261.1 (8741.61–9820.86)	−1.31 (−1.42 to −1.24)*	141.82 (125.82–156.88)	81.94 (72.55–91.37)	70.68 (62.56–78.62)	−2.26 (−2.32 to −2.2)*
GDB regions								
Southeast Asia, east Asia, and Oceania								
Southeast Asia	5265.93 (4924.59–5596.04)	3859.72 (3639.43–4088.74)	3291.9 (3102.28–3486.03)	−1.53 (−1.57 to −1.5)*	61.81 (55.1–70.9)	46.03 (38.94–50.07)	38.44 (32.69–42.59)	−1.53 (−1.58 to −1.5)*
East Asia	5487.52 (5158.03–5841.36)	3380.21 (3157.29–3648.3)	2861.01 (2675.65–3073.56)	−2.12 (−2.19 to −2.06)*	59.84 (52.46–65.62)	15.17 (13.06–18)	14.52 (12.24–17.43)	−4.58 (−4.69 to −4.46)*
Oceania	6784.04 (6353.93–7235.62)	4958.16 (4637.88–5290.07)	4183.73 (3907.45–4441.84)	−1.55 (−1.58 to −1.53)*	94.1 (81.58–107.6)	68.02 (57.34–82.08)	56.8 (47.54–70.33)	−1.63 (−1.68 to −1.59)*
Sub-Saharan Africa								
Western Sub-Saharan Africa	9131.44 (8575.28–9643.7)	8694.48 (8221.85–9185.03)	8000.21 (7571.15–8447.17)	−0.45 (−0.49 to −0.42)*	152.28 (134.1–171.29)	98.98 (83.99–114.83)	85.46 (71.01–99.8)	−1.87 (−1.91 to −1.85)*
Central Sub-Saharan Africa	10590.79 (9899.55–11313.73)	7349.03 (6895.41–7798.62)	7044.57 (6552.99–7611.53)	−1.3 (−1.33 to −1.27)*	169.84 (140.6–207.79)	114.14 (87.83–147.22)	106.69 (81.78–138.59)	−1.48 (−1.5 to −1.46)*
Southern Sub-Saharan Africa	9760.27 (9207.18–10279.67)	9590.11 (9053.17–10138.86)	8469.36 (7959.05–9004.17)	−0.56 (−0.72 to −0.4)*	97.33 (88.02–108.13)	95.39 (86.73–103.23)	76.29 (67.95–84.33)	−0.86 (−1.07 to −0.7)*
Eastern Sub-Saharan Africa	12929.45 (12197.69–13612.84)	9721.29 (9190.54–10267.51)	9102.47 (8589.4–9658.4)	−1.17 (−1.25 to −1.1)*	167.43 (146.48–186.92)	92.73 (82.06–104)	81.94 (72.4–90.62)	−2.37 (−2.49 to −2.28)*

(*continued on next page*)

Table 2 (*continued*)

	Incidence (/100,000)			AAPC (%, 95 % CI)	Death(/100,000)			AAPC (%, 95 % CI)
	1990	2019	2021		1990	2019	2021	
South Asia	17288.52 (16165.5–18335.03)	12032.06 (11348.25–12777.13)	11101.24 (10358.03–11891.17)	−1.48 (−1.63 to −1.39)*	74.99 (66.07–82.65)	46.81 (41.86–51.68)	39.19 (34.36–44.88)	−2.11 (−2.4 to −1.93)*
Latin America and Caribbean								
Tropical Latin America	6361.19 (6027.26–6722.74)	3686.99 (3476.79–3922.08)	3069.22 (2865.65–3305.22)	−2.29 (−2.44 to −2.16)*	53.37 (50.06–55.94)	41.8 (36.86–44.4)	32.81 (28.63–35.63)	−1.51 (−1.66 to −1.36)*
Caribbean	4097.96 (3868.12–4348.67)	2563.74 (2422.11–2727.96)	2061.57 (1950.33–2190.41)	−2.17 (−2.2 to −2.15)*	56.08 (51.51–60.99)	40.21 (35.98–44.75)	32.76 (28.63–37.08)	−1.7 (−1.82 to −1.6)*
Andean Latin America	6758.64 (6353.33–7177.8)	3453.5 (3240.13–3648.16)	3021.29 (2764.65–3245.56)	−2.69 (−2.94 to −2.57)*	111.55 (101.29–120.72)	66.36 (56.92–74.98)	52.24 (42.32–63.77)	−2.44 (−2.75 to −2.26)*
Central Latin America	3104.03 (2936.77–3286.9)	1547.19 (1464.24–1644.28)	1232.8 (1165.72–1308.55)	−2.94 (−2.97 to −2.91)*	48.41 (46.31–50.14)	28.11 (26.01–29.81)	21.93 (19.47–24.65)	−2.51 (−2.63 to −2.41)*
North Africa and Middle East	3525.58 (3290.77–3751.91)	2130.16 (2011.34–2259.38)	1856.96 (1756.17–1968.59)	−2.02 (−2.05 to −2)*	53.25 (47.85–60.58)	27.88 (24.62–30.94)	22.7 (19.91–25.6)	−2.7 (−2.73 to −2.66)*
Central Europe, eastern Europe, and central Asia								
Central Europe	1969.58 (1860.61–2102.97)	1143.16 (1078.85–1212.16)	888.44 (838.97–941.8)	−2.46 (−2.55 to −2.37)*	25.4 (24.37–26.16)	19.46 (18.29–20.19)	15.52 (14.22–16.49)	−1.37 (−1.56 to −1.2)*
Central Asia	3569.61 (3396.51–3762.59)	2340.24 (2217.82–2470.04)	1958.12 (1855.21–2064.65)	−1.82 (−1.88 to −1.73)*	63.7 (60.08–67.65)	30.9 (27.91–34.03)	23.34 (20.71–25.98)	−3.07 (−3.21 to −2.93)*
Eastern Europe	2634.8 (2445.87–2828.77)	1729.07 (1621.69–1844.4)	1526.6 (1429.48–1624.45)	−1.68 (−1.76 to −1.59)*	11.66 (11.37–11.94)	12.25 (11.8–12.72)	10.26 (9.44–11.2)	−0.1 (−0.4 to 0.19)
High-income regions								
High-income North America	1932.87 (1831.02–2049.22)	1279.99 (1219.02–1346.41)	1003.32 (949.94–1061.55)	−2.06 (−2.11 to −2.01)*	21.61 (19.24–22.92)	11.14 (9.74–11.91)	8.82 (7.63–9.5)	−2.64 (−2.82 to −2.47)*
High-income Asia Pacific	1501.97 (1401.58–1620.06)	815.44 (752.64–884.63)	636.21 (588.4–687.5)	−2.73 (−2.76 to −2.7)*	40.6 (36.05–42.88)	18.06 (15.25–19.77)	14.35 (12.01–15.72)	−3.38 (−3.61 to −3.2)*
Australasia	994.91 (927.17–1070.6)	646.38 (606.48–689.85)	497.38 (465.96–530.22)	−2.3 (−2.54 to −2.15)*	13.73 (12.19–14.74)	9.25 (7.74–10.16)	6.7 (5.53–7.39)	−2.37 (−2.86 to −1.87)*
Western Europe	903.73 (855.72–961.7)	660.16 (622.57–702.19)	524.62 (493.86–556.67)	−1.71 (−1.74 to −1.68)*	20.51 (18.47–21.55)	13.42 (11.53–14.42)	10.01 (8.49–10.8)	−2.19 (−2.39 to −2.01)*
Southern Latin America	2316.07 (2177.8–2467.44)	1938.23 (1827.29–2078.62)	1563.36 (1474.01–1660.84)	−1.35 (−1.51 to −1.2)*	37.02 (34.47–38.57)	55.95 (50.73–59.09)	39.43 (35–42.34)	0.33 (−0.1 to 0.6)

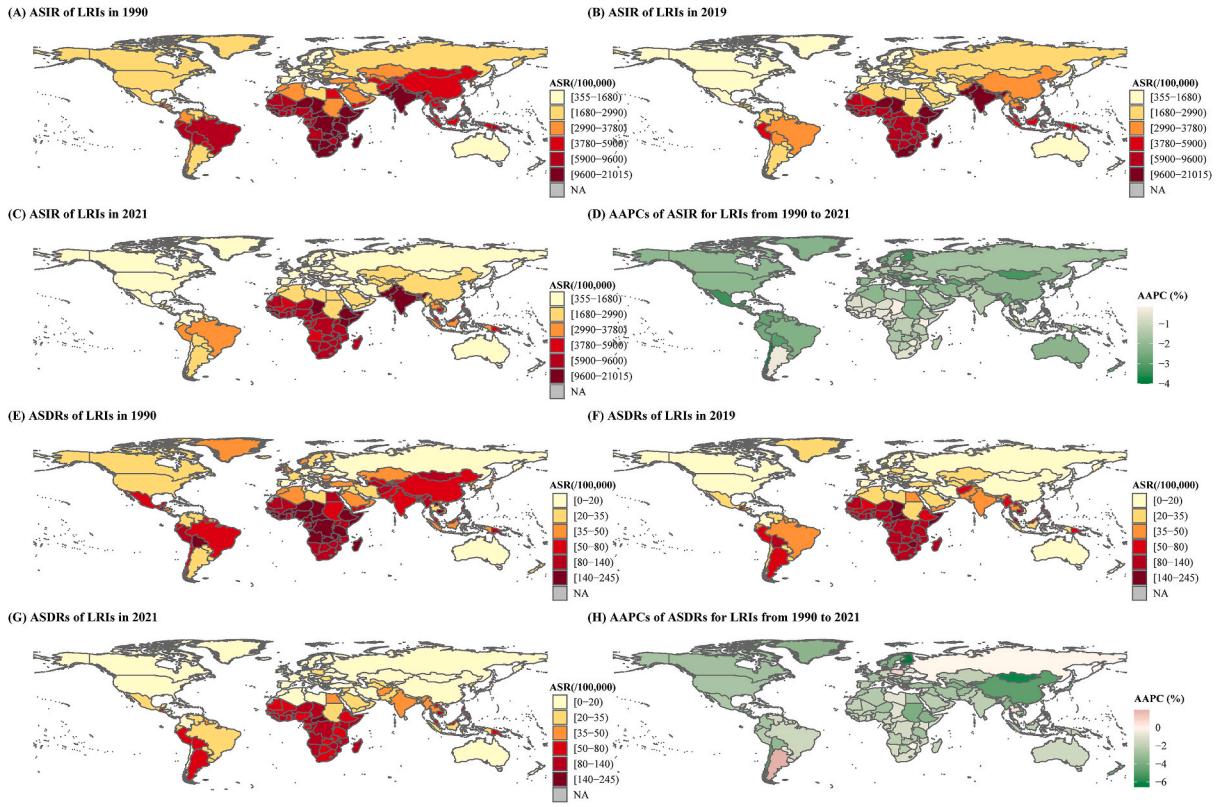

Fig. 2. Global Incidence and Deaths rates of Lower Respiratory Infections among 204 Countries and Territories. (A) ASIR in 1990; (B) ASIR in 2019; (C) ASIR in 2021; (D) AAPC in ASIR from 1990 to 2021; (E) ASDR in 1990; (F) ASDR in 2019; (G) ASDR in 2021; (H) AAPC in ASDR from 1990 to 2021.

Streptococcus pneumoniae is prone to infect children, elderly individuals, and individuals with compromised immune systems [30]. A study indicates that infections with viruses such as influenza and RSV frequently lead to Streptococcus pneumoniae superinfection [31]. The severe mortality burden may be associated with secondary serious complications. With respect to the burden of LRIs, pneumococcus has emerged as the primary cause of DALYs globally [32]. *Staphylococcus aureus* acts as both a commensal and a pathogenic bacterium in humans. Its capacity to incite severe LRIs is rooted in a diverse array of virulence factors, making it a significant contributor to the severity of such infections [33,34]. During 2020–2021, influenza and RSV viruses, significant contributors to deaths related to LRIs, showed a decrease in the proportion of mortality cases. This decline is likely linked to the implementation of non-pharmaceutical interventions (NPIs) during the COVID-19 pandemic [35]. As NPIs are relaxed, there may be a resurgence in LRIs-related due to influenza and RSV viruses, requiring significant attention. Currently, LRIs continue to be a significant contributor to global morbidity and mortality. Enhancing access to existing vaccines and introducing novel vaccines and treatments, particularly in resource-limited settings, is essential for reducing fatalities associated with LRIs. Additionally, it is crucial to remain vigilant and proactively address the growing issue of microbial resistance [35].

Following the COVID-19 pandemic, there has been a significant decrease in the ASIR and ASDRs of respiratory infections across most regions, especially LRIs. One of the primary reasons for this decline could be the implementation of varying degrees of NPIs prompted by the COVID-19 pandemic, such as social distancing, mask-wearing, and maintaining personal hygiene at the individual, community, environmental and country levels. These measures have not only curtailed the ongoing spread of COVID-19 but also interrupted the transmission of numerous respiratory infections [36,37]. However, the most significant increase in the ASIR of URIs was observed during the COVID-19 pandemic in high- and low- SDI regions. This could be due to differences in the implementation of COVID-19 interventions in different countries, and the relaxation of NPIs might lead to the resurgence of respiratory diseases [38,39]. For example, in the USA, a state of emergency was declared on March 13, 2020, and was quickly lifted on March 29 [38]. In early 2020, Western Australia closed its state and international borders. By mid-2020, after successfully eliminating local transmission of SARS-CoV-2, internal NPIs were reduced, allowing for large-scale gatherings and the absence of mask wearing. Following the reduction in NPIs, there was a significant increase in pediatric respiratory admissions related to human parainfluenza virus in Western Australia in 2021 [40]. However, the effects of various global public health measures implemented during the COVID-19 pandemic on the incidence, deaths, and mechanisms of URIs and LRIs, as well as their long-term effects, still require further research and exploration.

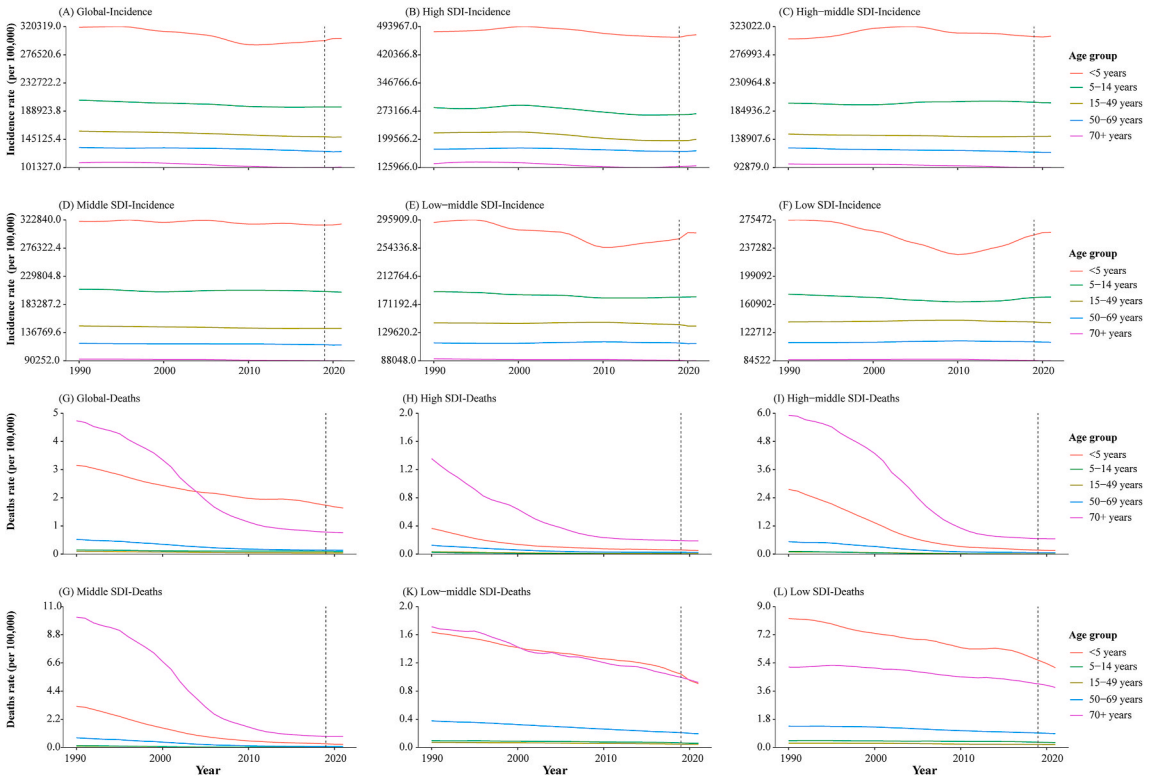

Fig. 3. Age-specific Incidence and Trends of Upper Respiratory Infections from 1990 to 2019 among Each SDI Regions. (A) Global incidence; (B) Incidence in high SDI regions; (C) Incidence in high-middle SDI regions; (D) Incidence in middle SDI regions; (E) Incidence in low-middle SDI regions; (F) Incidence in low SDI regions; (G) Global deaths; (H) Deaths in high SDI regions; (I) Deaths in high-middle SDI regions; (J) Deaths in middle SDI regions; (K) Deaths in low-middle SDI regions; (L) Deaths in low SDI regions.

5.1. Limitations and suggestions

Our study has several limitations that should be acknowledged. We have documented the incidence and deaths of URIs and LRIs in 2020 and 2021. However, the impact of COVID-19 on URIs and LRIs, as well as its mechanisms, requires further exploration and research. Additionally, during the COVID-19 pandemic, the incidence of URIs has significantly increased in both high and low SDI regions. Furthermore, in 2021, the incidence of URIs in females has surpassed that of males, and the specific reasons for these trends need further investigation. Researchers are encouraged to persist in their inquiry into the lasting effects of COVID-19 on the incidence and deaths of URIs and LRIs. Furthermore, an analysis of the effectiveness of NPIs enforced throughout this period would be beneficial. These efforts will provide additional crucial insights for the prevention and management of URIs and LRIs.

6. Conclusion

Despite a decline in the global ASIR and ASDRs of ARIs over the past 32 years, ARIs continue to impose a significant burden. It remains a significant public health concern, particularly due to the notable incidence of URIs in high SDI regions and the deaths associated with both URIs and LRIs in low SDI regions. The incidence and deaths remain high among children under 5 years old and individuals over 70 years old. Additionally, an increase in the incidence of URIs was observed in both high- and low-SDI regions during the COVID-19 pandemic, necessitating increased attention.

Ethics approval and consent to participate

The study did not require ethics approval and consent to participate because it used publicly available data.

Consent for publication

Not applicable.

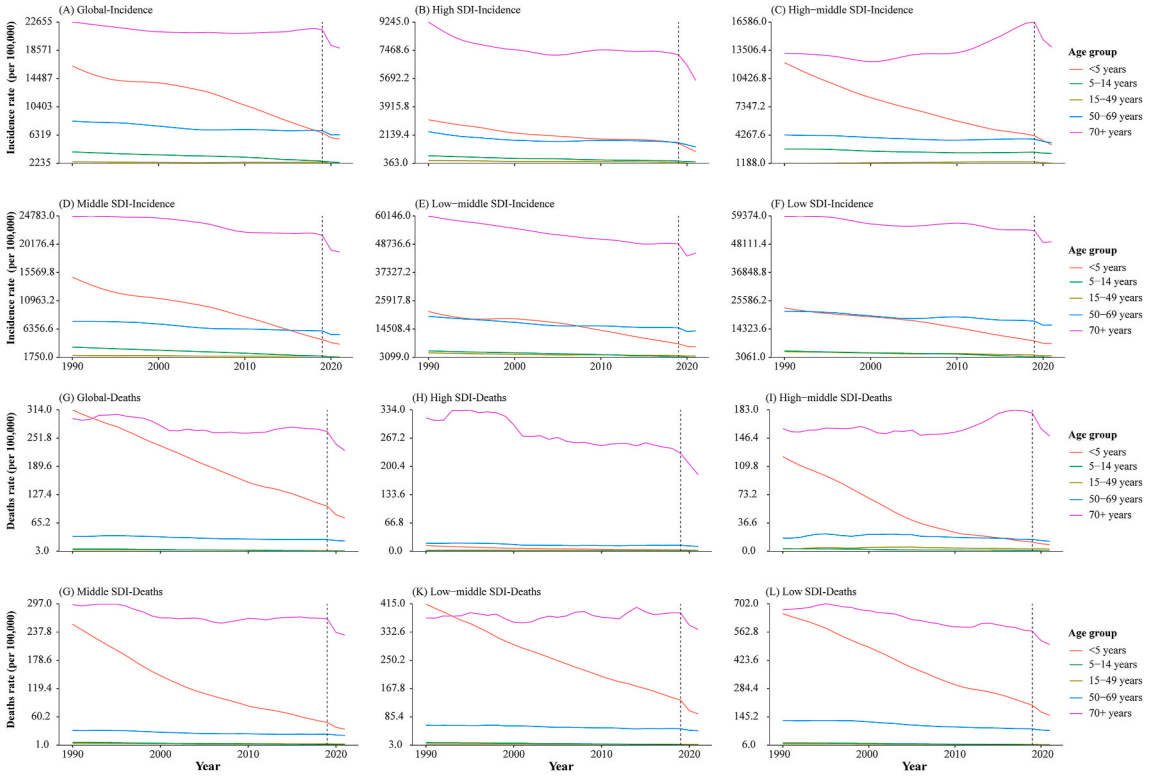

Fig. 4. Age-specific Deaths and Trends of Lower Respiratory Infections from 1990 to 2019 among Each SDI Regions. (A) Global death; (B) Death in high SDI regions; (C) Death in high-middle SDI regions; (D) Death in middle SDI regions; (E) Death in low-middle SDI regions; (F) Death in low SDI regions; (G) Global deaths; (H) Deaths in high SDI regions; (I) Deaths in high-middle SDI regions; (J) Deaths in middle SDI regions; (K) Deaths in low-middle SDI regions; (L) Deaths in low SDI regions.

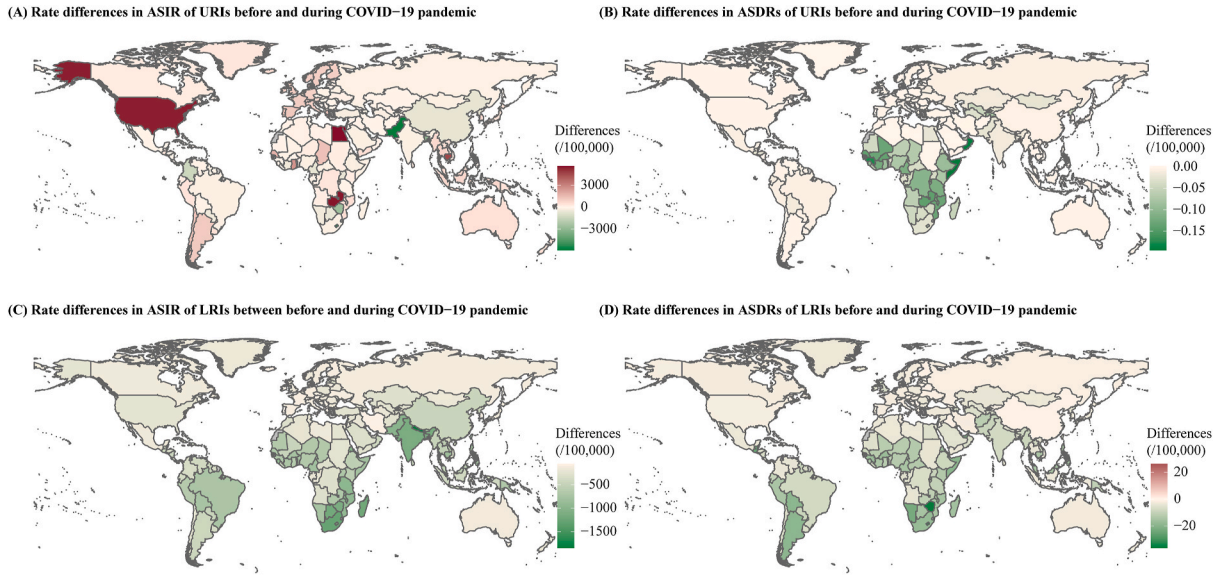

Fig. 5. Rate Differences in the Incidence and Deaths of ARIs Before and After the COVID-19 pandemic. (A) Rate differences in ASIR of URIs; (B) Rate differences in ASDRs of URIs; (C) Rate differences in ASIR of LRIs; (D) Rate differences in ASDR of LRIs.

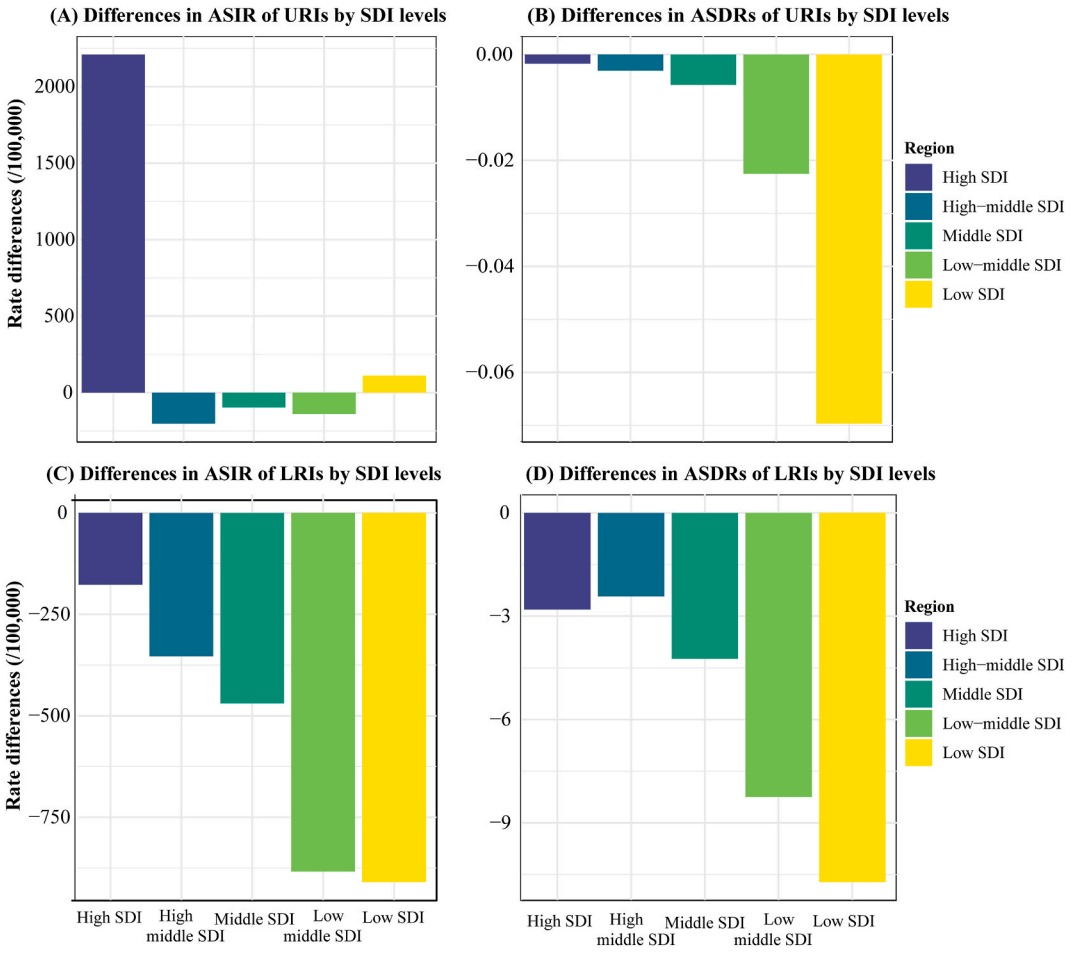

Fig. 6. Rate Differences in the Incidence and Deaths of ARIs by SDI Levels. (A) Rate differences in ASIR of URIs by SDI Levels; (B) Rate differences in ASDR of URIs by SDI Levels; (C) Rate differences in ASIR of LRIs by SDI Levels; (D) Rate differences in ASDR of LRIs by SDI Levels; Supplementary Materials.

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Data availability statement

Publicly available datasets (Global Burden of Disease study 2021) were analyzed in this study. The data can be found here: http://ghdx.healthdata.org/gbd-results-tool.

CRediT authorship contribution statement

Can Chen: Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation. **Yue You:** Writing – original draft, Formal analysis, Data curation. **Yuxia Du:** Visualization, Validation, Formal analysis. **Wenkai Zhou:** Writing – original draft, Visualization, Validation. **Daixi Jiang:** Validation, Data curation. **Kexin Cao:** Validation, Data curation. **Mengya Yang:** Validation, Data curation. **Xiaoyue Wu:** Validation, Data curation. **Mengsha Chen:** Validation, Data curation. **Jiaxing Qi:** Validation, Data curation. **Dingmo Chen:** Validation, Data curation. **Rui Yan:** Validation, Data curation. **Dong Yan:** Writing – review & editing, Conceptualization. **Mingxia Ji:** Writing – review & editing, Conceptualization. **Shigui Yang:** Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e35841.

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