# Global burden of lower respiratory infections and aetiologies, 1990–2023: a systematic analysis for the Global Burden of Disease Study 2023

*GBD 2023 Lower Respiratory Infections and Antimicrobial Resistance Collaborators**

## Summary

**Background** Lower respiratory infections (LRIs) remain the world's leading infectious cause of death. This analysis from the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) 2023 provides global, regional, and national estimates of LRI incidence, mortality, and disability-adjusted life-years (DALYs), with attribution to 26 pathogens, including 11 newly modelled pathogens, across 204 countries and territories from 1990 to 2023. With new data and revised modelling techniques, these estimates serve as an update and expansion to GBD 2021. Through these estimates, we also aimed to assess progress towards the 2025 Global Action Plan for the Prevention and Control of Pneumonia and Diarrhoea (GAPPD) target for pneumonia mortality in children younger than 5 years.

**Methods** Mortality from LRIs, defined as physician-diagnosed pneumonia or bronchiolitis, was estimated using the Cause of Death Ensemble model with data from vital registration, verbal autopsy, surveillance, and minimally invasive tissue sampling. The Bayesian meta-regression tool DisMod-MR 2.1 was used to model overall morbidity due to LRIs. DALYs were calculated as the sum of years of life lost (YLLs) and years lived with disability (YLDs) for all locations, years, age groups, and sexes. We modelled pathogen-specific case-fatality ratios (CFRs) for each age group and location using splined binomial regression to create internally consistent estimates of incidence and mortality proportions attributable to viral, fungal, parasitic, and bacterial pathogens. Progress was assessed towards the GAPPD target of less than three deaths from pneumonia per 1000 livebirths, which is roughly equivalent to a mortality rate of less than 60 deaths per 100 000 children younger than 5 years.

**Findings** In 2023, LRIs were responsible for 2·50 million (95% uncertainty interval [UI] 2·24–2·81) deaths and 98·7 million (87·7–112) DALYs, with children younger than 5 years and adults aged 70 years and older carrying the highest burden. LRI mortality in children younger than 5 years fell by 33·4% (10·4–47·4) since 2010, with a global mortality rate of 94·8 (75·6–116·4) per 100 000 person-years in 2023. Among adults aged 70 years and older, the burden remained substantial with only marginal declines since 2010. A mortality rate of less than 60 deaths per 100 000 for children younger than 5 years was met by 129 of the 204 modelled countries in 2023. At a super-regional level, sub-Saharan Africa had an aggregate mortality rate in children younger than 5 years (hereafter referred to as under-5 mortality rate) furthest from the GAPPD target. *Streptococcus pneumoniae* continued to account for the largest number of LRI deaths globally (634 000 [95% UI 565 000–721 000] deaths or 25·3% [24·5–26·1] of all LRI deaths), followed by *Staphylococcus aureus* (271 000 [243 000–298 000] deaths or 10·9% [10·3–11·3]), and *Klebsiella pneumoniae* (228 000 [204 000–261 000] deaths or 9·1% [8·8–9·5]). Among pathogens newly modelled in this study, non-tuberculous mycobacteria (responsible for 177 000 [95% UI 155 000–201 000] deaths) and *Aspergillus spp* (responsible for 67 800 [59 900–75 900] deaths) emerged as important contributors. Altogether, the 11 newly modelled pathogens accounted for approximately 22% of LRI deaths.

**Interpretation** This comprehensive analysis underscores both the gains achieved through vaccination and the challenges that remain in controlling the LRI burden globally. Furthermore, it demonstrates persistent disparities in disease burden, with the highest mortality rates concentrated in countries in sub-Saharan Africa. Globally, as well as in these high-burden locations, the under-5 LRI mortality rate remains well above the GAPPD target. Progress towards this target requires equitable access to vaccines and preventive therapies—including newer interventions such as respiratory syncytial virus monoclonal antibodies—and health systems capable of early diagnosis and treatment. Expanding surveillance of emerging pathogens, strengthening adult immunisation programmes, and combating vaccine hesitancy are also crucial. As the global population ages, the dual challenge of sustaining gains in child survival while addressing the rising vulnerability in older adults will shape future pneumonia control strategies.

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## Research in context

### Evidence before this study

The global burden of lower respiratory infections (LRIs) and their aetiologies has been quantified by different groups, including the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) and WHO and the Maternal and Child Epidemiology Estimation Group. We conducted a PubMed search using the search string ("lower respiratory" [title] or "pneumonia" [title]) AND ("mortality" OR "incidence") AND "risk factors" AND "global" to identify studies published from database inception to June 17, 2025. Of the 203 results, 29 reported global estimates of LRIs, covering a range of one to 18 pathogens. The most comprehensive study to date has been the GBD 2021 LRI report, which estimated 2·18 million (95% uncertainty interval [UI] 1·98–2·36) deaths attributable to non-COVID-19 LRI in 2021, or 27·7 (25·1–29·9) deaths per 100 000 person-years, with *Streptococcus pneumoniae* as the leading aetiology.

### Added value of this study

GBD 2023 incorporates many more data sources than GBD 2021 for quantifying the mortality, morbidity, and pathogen-specific burden of LRIs across 204 countries and territories, from 1990 to 2023, enabling more comprehensive and accurate estimates. GBD 2023 has introduced quantification of several new LRI aetiologies: *Aspergillus* spp, *Citrobacter* spp, group A streptococcus, *Morganella* spp, other *Acinetobacter* spp, other fungi, other Gram-negative bacteria, other *Klebsiella* spp, other *Mycobacterium* spp (non-tuberculosis or leprosy), *Proteus* spp, *Serratia* spp, and a residual category of other bacterial and viral pathogens. To the best of our knowledge, this study provides the first comprehensive global and national estimates of the LRI burden attributable to these newly modelled pathogens. In addition to describing the burden of these new aetiologies, we have incorporated new data to update the analyses for previously modelled aetiologies. Moreover, using the results from GBD 2023, we evaluated progress towards the 2025 pneumonia mortality target set by the Global Action Plan for Prevention and Control of Pneumonia and Diarrhoea (GAPPD) of less than three deaths per 1000 livebirths per year, which is roughly equivalent to a mortality rate of less than 60 deaths per 100 000 children younger than 5 years.

### Implications of all the available evidence

Although substantial reductions in LRI mortality rates have been achieved in children younger than 5 years, the 2023 global rate of 94·8 (95% UI 75·6–116·4) deaths per 100 000 still falls short of the mortality target set by the GAPPD. Concerted efforts to improve access to health care and expand vaccination programmes for key pathogens, such as *Streptococcus pneumoniae* and *Haemophilus influenzae* type b, alongside the introduction of innovative interventions such as respiratory syncytial virus vaccines, could help to further reduce the burden of LRIs in children younger than 5 years. Additionally, the burden of LRIs among older adults remains substantial. The mortality rate of LRIs in 2023 was highest in adults aged 70 years and older, at 231·6 deaths (201·1–262·2) per 100 000, underscoring the need for targeted interventions, including early diagnosis, timely treatment, and expanded vaccination coverage. Emerging pathogens such as non-tuberculous mycobacteria are increasingly recognised as key contributors to the LRI burden, emphasising the importance of enhanced diagnostics and surveillance.

## Introduction

Lower respiratory infections (LRIs) excluding COVID-19 are the leading infectious cause of death globally and contribute substantially to mortality and disability worldwide. In 2023, LRIs excluding COVID-19 were the fourth leading cause of death globally across all ages, the fifth leading cause in adults older than 70 years, and the second leading cause in children younger than 5 years.[1] Population differences in access to resources, such as income and health care, and exposure to environmental pollution drive substantial socioeconomic disparities in disease burden.[2,3] Among children younger than 5 years in 2021, the LRI mortality rate excluding COVID-19 was 80 times greater in the lowest Socio-demographic Index (SDI) quintile versus the highest.[4]

Dozens of bacterial, viral, and fungal pathogens can cause pneumonia. Community-acquired bacterial pneumonia is frequently attributable to *Streptococcus pneumoniae*; other classic bacterial pathogens include *Haemophilus influenzae* and the atypical bacteria *Mycoplasma pneumoniae, Chlamydia* spp, *and Legionella* spp.[4,5] A 2023 global meta-analysis estimated that among cases of severe pneumonia, 8·1% (95% CI 6·3–10·1) were attributable to *M pneumoniae*, *Chlamydia* spp, and *Legionella* spp, with the prevalence of these atypical species ranging from 0% to 48·1% across included studies.[6] Additionally, *Staphylococcus aureus* is increasingly recognised as an aetiology of severe community-acquired LRI, both meticillin-sensitive *S aureus* (MSSA) and meticillin-resistant *S aureus* (MRSA) strains, particularly in the setting of post-viral pneumonia.[7,8] Viruses such as influenza and respiratory syncytial virus (RSV) are highly prevalent causes of LRI. The clinical courses of these viruses range from benign to highly morbid and are frequently complicated by co-infections with bacterial pathogens, which exacerbate clinical severity and worsen outcomes.[9,10] Health-care-associated pneumonia frequently involves multidrug-resistant Gram-negative bacteria, including *Klebsiella* spp, *Pseudomonas aeruginosa*, and *Acinetobacter* spp.[4,11] Finally, opportunistic pathogens such as *Aspergillus* spp and non-tuberculous mycobacteria can cause clinically significant infections in select groups,

particularly immunocompromised patients and those with pre-existing lung disease.[12,13]

The integrated Global Action Plan for Prevention and Control of Pneumonia and Diarrhoea (GAPPD), published in 2013 by UNICEF and WHO, outlined recommendations to address pneumonia alongside diarrhoea to reduce early childhood mortality. Key GAPPD goals for 2025 included reducing pneumonia mortality in children younger than 5 years to less than three deaths per 1000 livebirths and achieving from 2010 a 75% reduction in the incidence of severe pneumonia in children younger than 5 years.[14] Additionally, the GAPPD set targets related to pneumonia risk factors, including 90% full-dose coverage of vaccinations in infants by age 1 year and access to appropriate pneumonia case management in 90% of children younger than 5 years.[14]

In recent decades, LRI incidence and mortality have fallen substantially, especially in very young children.[4] This progress is multifactorial, including reduced exposure to risk factors, improved access to health care, and the widespread rollout of vaccination against key LRI pathogens—*S pneumoniae, H influenzae* type b, influenza, and most recently, RSV.[15] As the longevity of the global population continues to increase, older adults comprise a larger proportion of the LRI burden worldwide. By 2050, the population of adults aged older than 70 years is expected to be 1·16 billion.[16] Immune dysfunction, frailty, and the presence of multiple comorbidities contribute to rising LRI case-fatality ratios (CFRs) with age.[17,18]

The most recent iteration of the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD), GBD 2021, presented results for 18 LRI aetiologies across 204 countries and territories from 1990 to 2021. The current study aimed to expand this scope to provide comprehensive estimates of the burden of LRIs for 26 aetiologies across 204 countries and territories from 1990 to 2023. We also aimed to assess progress towards the 2025 GAPPD target for pneumonia mortality. This manuscript was produced as part of the GBD Collaborator Network and in accordance with the GBD Protocol.

## Methods

### Overview

GBD is a systematic, scientific effort that quantifies morbidity and mortality attributable to diseases, injuries, and risk factors across time for granular age groups, sexes, and locations. GBD creates estimates for 204 countries and territories that are further organised into 21 regions according to geographical proximity or other epidemiological similarities. These regions are grouped into seven larger super-regions for analytical purposes. A more detailed explanation of each of the GBD methodologies and estimation processes has been published elsewhere.[1,3,19] The University of Washington Institutional Review Board Committee approved this study (Study ID 9060). The study is approved until July 23, 2026. Morbidity and mortality for each LRI aetiology were estimated up to 2023 using data and modelling strategies used in the antimicrobial resistance study of the GBD 2021 Antimicrobial Resistance Collaborators.[20]

For the purpose of this study, LRI is defined as physician-diagnosed pneumonia or bronchiolitis. The International Classification of Diseases (ICD) codes that correspond to LRI within the GBD framework are listed in appendix 1 (p 9). Tuberculosis, pertussis, and COVID-19 are modelled as separate entities from LRI because of their distinct public health significance and are not included in the definition of LRI within the GBD framework.

See Online for appendix 1

For more information on input data and sources, the GBD Sources tool on the Global Health Data Exchange (GHDx) provides all metadata to identify which sources were used for any of the GBD estimates. This research complies with the GATHER statement (appendix 1 p 100).

For more on the **GHDx** see https://ghdx.healthdata.org/gbd-2023

### Mortality estimation process

Mortality for LRIs was estimated with the Cause of Death Ensemble model (CODEm) using data from vital registration, verbal autopsy, surveillance, and minimally invasive tissue sampling.[1] LRI mortality estimates were derived from a total of 24 082 site-years: 20 261 site-years from viral registration, 953 from sample vital registration, 2177 from verbal autopsy, 681 from surveillance, and ten from minimally invasive tissue sampling.[1] CODEm operates with an array of sub-models with multiple combinations of different predictor covariates to create the outcome variable (mortality rate or cause fractions). The array includes linear mixed-effects models with random intercepts at the super-region, region, and country levels, and spatiotemporal Gaussian process regression models. The final selection of CODEm's ensemble of models was made with the model that performed best in out-of-sample predictive validity tests. A complete list of the covariates used in the LRI model is provided in appendix 1 (pp 7–8). Through the LRI mortality estimates we also assessed progress towards the GAPPD target of fewer than three pneumonia deaths per 1000 livebirths in children younger than 5 years, which is roughly equivalent to a mortality rate of less than 60 deaths per 100 000 children younger than 5 years. The GAPPD targets were published in 2013, with a baseline year of 2010 and a target year of 2025. Our study includes results up to the year 2023 and uses 2010 as a baseline for comparison for ease of benchmarking with the GAPPD study.

### Morbidity estimation process

Data used to estimate LRI morbidity came from a systematic review (appendix 1 pp 9–13) of published studies, surveillance data, cause-specific mortality estimates, claims data, and inpatient data. A total of 1062 morbidity sources were used to create non-fatal

estimates for LRI in GBD 2023, of which 135 were new sources. A standardised adjustment was applied using a meta-regression tool to adjust alternative case definitions from different sources (survey, hospital literature, clinical inpatient, and claims data) to match our gold standard case definition of LRI, which is physician-diagnosed pneumonia or bronchiolitis (appendix 1 pp 11–12). The Bayesian meta-regression tool DisMod-MR 2.1 was used to model overall morbidity due to LRIs. A more detailed explanation of DisMod-MR 2.1 can be found in previous studies.[3,19]

### Disability-adjusted life-year (DALY) estimation process

We calculated DALYs as the sum of years of life lost (YLLs) and years lived with disability (YLDs) for all locations, years, and age groups, and both sexes. YLLs are calculated as the sum of each LRI death multiplied by the standard life expectancy for each age. YLDs are calculated by multiplying the prevalence of each LRI severity level by its respective disability weight. For more information on LRI disability weights, see appendix 1 (pp 13–14) and previous publications.[21] For a more detailed explanation of the calculation of DALYs, YLLs, and YLDs, see previous publications.[3,19]

### Aetiology estimation process

We estimated mortality and incidence attributable to the following pathogen categories: *Acinetobacter baumannii*, *Aspergillus* spp, *Chlamydia* spp, *Citrobacter* spp, *Enterobacter* spp, *Escherichia coli*, group A streptococcus, group B streptococcus, *H influenzae*, influenza, *Klebsiella pneumoniae*, *Legionella* spp, *Morganella* spp, *Mycoplasma* spp, other *Acinetobacter* species, other *Klebsiella* species, other *Mycobacterium* species (non-tuberculosis, non-leprosy), other fungi, other Gram-negative bacteria, *Proteus* spp, *P aeruginosa*, RSV, *Serratia* spp, *S aureus*, *S pneumoniae*, and a residual category for other bacterial and viral pathogens (appendix 2 table S9). "Other" categories are defined as residual, aggregate pathogen categories not otherwise modelled with more granularity (eg, "other *Klebsiella* spp" refers to *Klebsiella* spp other than *K pneumoniae*). Data used in the aetiology estimation process included multiple causes of death data; hospital discharge, linkage, and microbial data; data derived from searches of the literature; and mortality surveillance data (Child Health and Mortality Prevention Surveillance; appendix 1 p 14). A more comprehensive description of the process for estimating LRI aetiology can be found in previous studies.[20] Notably, the research describes pathogen distributions for multiple infectious syndromes, of which LRI is one. Although the different models share the same estimation methodologies, the data and results are independent by syndrome.

See Online for appendix 2

In summary, once data were extracted and processed, pathogen distributions were assessed using the multinomial estimation with partial and composite observations modelling environment, allowing for the inclusion of covariates in the network analysis[20] and incorporation of Bayesian priors (appendix 1 pp 23–28). We estimated the incidence and death proportions attributable to viral, fungal, parasitic, and bacterial pathogens, and used modelled CFRs, as described below, to maximally leverage mortality-only data sources to estimate implied cases for incidence estimation. Data showing clear linkage between pathogen-specific disease incidence and deaths were used to develop models for pathogen-specific CFRs for each age, location, and syndrome. A splined binomial regression was implemented with the RegMod modelling environment to estimate pathogen-specific CFRs as a function of the Healthcare Access and Quality (HAQ) Index and other covariates. Finally, the estimated CFR was used to calculate mortality proportions from incidence proportions as modelled above. In the GBD framework, every case or death due to LRI is assigned a pathogen given the estimated distribution (ie, we do not model a category of cases or deaths due to an unknown pathogen; we assign all to a category based on the underlying distribution in the population). For a more detailed explanation, including covariates, priors, exceptions, and validations of the model, see appendix 1 (pp 14–33).

### Calculation of uncertainty intervals and presentation of results

95% uncertainty intervals (UIs) were calculated as the 2·5th and 97·5th percentiles across all draws. Count estimates have been presented to three significant figures, while rates and percentages have been presented to one decimal place.

### Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

## Results

### Overall LRI mortality, morbidity, and DALY estimates

Globally, LRIs were responsible for 2·50 million (95% UI 2·24–2·81) deaths and an all-age mortality rate of 31·0 (27·8–34·9) per 100 000 person-years in 2023 (table 1)—a substantial decline from 1990, when deaths reached 2·97 million (2·64–3·34) and the all-age mortality rate was 55·7 (49·5–62·5) per 100 000 (figure 1). During the pandemic years of 2020–21, global deaths caused by LRIs declined to 2·21 million (1·97–2·51) in 2020 and 2·12 million (1·87–2·42) in 2021 (figure 1). Between 2010 and 2023, there was a 33·4% (10·4–47·4) decrease in the LRI mortality rate among children younger than 5 years—the age group highlighted in the GAPPD target (table 1; appendix 2 table S1). In adults aged 70 years and older, there was a decrease of 10·2% (3·1–22·1) in LRI mortality rates during the same period (table 1).

The largest mortality rate among the five age groups included in this analysis in 2023 was in adults aged 70 years and older, at 231·6 (95% UI 201·1–262·2) per 100 000 (table 1; figure 2). The second largest mortality

| | 2010 | | 2023 | | Percentage change in mortality rates between 2010 and 2023 |
|---|---|---|---|---|---|
| | Deaths | Mortality rate per 100 000 | Deaths | Mortality rate per 100 000 | |
| All ages | 2 440 000 (2 160 000 to 2 700 000) | 35·0 (31·0 to 38·8) | 2 500 000 (2 240 000 to 2 810 000) | 31·0 (27·8 to 34·9) | –11·4% (–23·7 to 2·4) |
| <5 years | 936 000 (765 000 to 1 130 000) | 142·4 (116·3 to 171·5) | 610 000 (486 000 to 749 000) | 94·8 (75·6 to 116·4) | –33·4% (–47·4 to –10·4) |
| 5–14 years | 81 000 (64 700 to 102 000) | 6·6 (5·3 to 8·4) | 79 300 (62 900 to 102 000) | 5·7 (4·5 to 7·3) | –13·7% (–36·5 to 21·1) |
| 15–49 years | 182 000 (154 000 to 212 000) | 5·0 (4·2 to 5·8) | 197 000 (163 000 to 241 000) | 4·9 (4·1 to 6·0) | –1·5% (–21·1 to 28·8) |
| 50–69 years | 300 000 (259 000 to 344 000) | 28·2 (24·3 to 32·3) | 367 000 (317 000 to 430 000) | 24·5 (21·2 to 28·7) | –13·0% (–27·8 to 10·6) |
| ≥70 years | 936 000 (799 000 to 1 040 000) | 258·0 (220·3 to 287·5) | 1 250 000 (1 080 000 to 1 410 000) | 231·6 (201·1 to 262·2) | –10·2% (–22·1 to 3·1) |

Data in parentheses are 95% uncertainty intervals. Count data are presented to three significant figures, and rates and percentages are presented to one decimal place. 2010 estimates are included alongside 2023 estimates because the GAPPD goals, published in 2013, use a baseline year of 2010; this presentation facilitates comparison to GAPPD benchmarks. Values for 1990 are briefly presented in figure 1 and can be further explored in the online GBD Results Tool. GAPPD=Global Action Plan for Prevention and Control of Pneumonia and Diarrhoea.

***Table 1:*** **Fatal estimates of lower respiratory infection globally by age in 2010 and 2023**

rate was seen in children younger than 5 years, at 94·8 (75·6–116·4) per 100 000 (table 1). In 2010, adults aged 70 years and older also had the highest mortality rate, at 258·0 (220·3–287·5) per 100 000, and children younger than 5 years accounted for the second highest mortality rate, at 142·4 (116·3–171·5) per 100 000 (table 1; figure 2).

Across all ages, LRI was responsible for a higher mortality rate and more deaths in males, accounting for 1·33 million (1·17–1·53) deaths and a mortality rate of 32·8 (28·9–37·8) per 100 000, compared with females, who accounted for 1·17 million (0·983–1·42) deaths and a mortality rate of 29·2 (24·5–35·3) per 100 000 (figure 1; appendix 2 table S3). The location with the largest all-age LRI mortality rate in 2023 was Niger (118·6 [90·2–153·6] per 100 000), followed by Laos (111·2 [83·9–144·9] per 100 000) and the Central African Republic (104·1 [78·8–137·9] per 100 000; appendix 2 table S3). When compared to the GAPPD target of a mortality rate of less than 60 per 100 000, 129 of the 204 modelled countries and territories met this target for children younger than 5 years in 2023 (figure 3). At a super-regional level, sub-Saharan Africa had an aggregate under-5 LRI mortality rate furthest from the GAPPD target (figure 3).

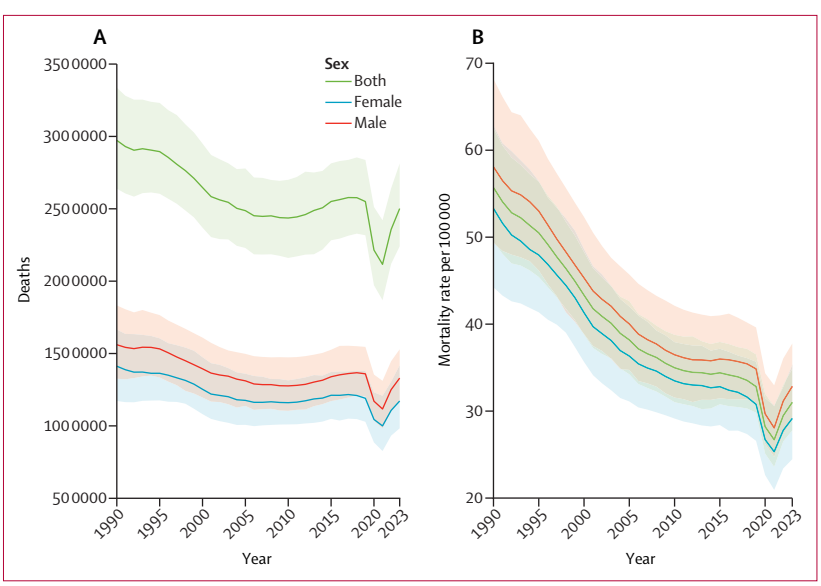


***Figure 1:*** **All-age LRI deaths (A) and mortality rate per 100 000 (B) from 1990 to 2023**
The shaded area around each line represents 95% uncertainty intervals. LRI=lower respiratory infection.

Globally, there were 242 million (95% UI 228–258) LRI incident episodes in 2023, with an all-age incidence rate of 3001·7 (2830·3–3204·6) per 100 000 (appendix 2 table S8). Between 2010 and 2023, there was a 39·8% (37·8–41·5) decrease in the LRI incidence rate in children younger than 5 years (appendix 2 table S1). LRIs were also responsible for 98·7 million (87·7–112) DALYs, with an all-age rate of 1223·8 (1087·9–1388·8) per 100 000 globally in 2023 (table 2). When splitting DALYs into YLLs and YLDs, LRIs were responsible for 98·4 million (87·4–112) YLLs and 291 000 (200 000–414 000) YLDs (appendix 2 table S2). The largest number of DALYs globally in 2023 came from children younger than 5 years, at 54·4 million (43·4–66·8) DALYs, with a rate of 8454·8 (6748·8–10 381·7) per 100 000 (table 2; appendix 2 figure S2). In 2010, children younger than 5 years had a DALY rate of 12 697·9 (10 373·1–15 274·5) per 100 000; this represents a decrease of 33·4% (10·4–47·3) between 2010 and 2023 (table 2). In adults aged 70 years and older, the total number of global DALYs reached 16·0 million (13·9–18·3) in 2023, with a DALY rate of 2974·8 (2580·0–3390·6) per 100 000 (table 2). In 2010, adults aged 70 years and older accounted for

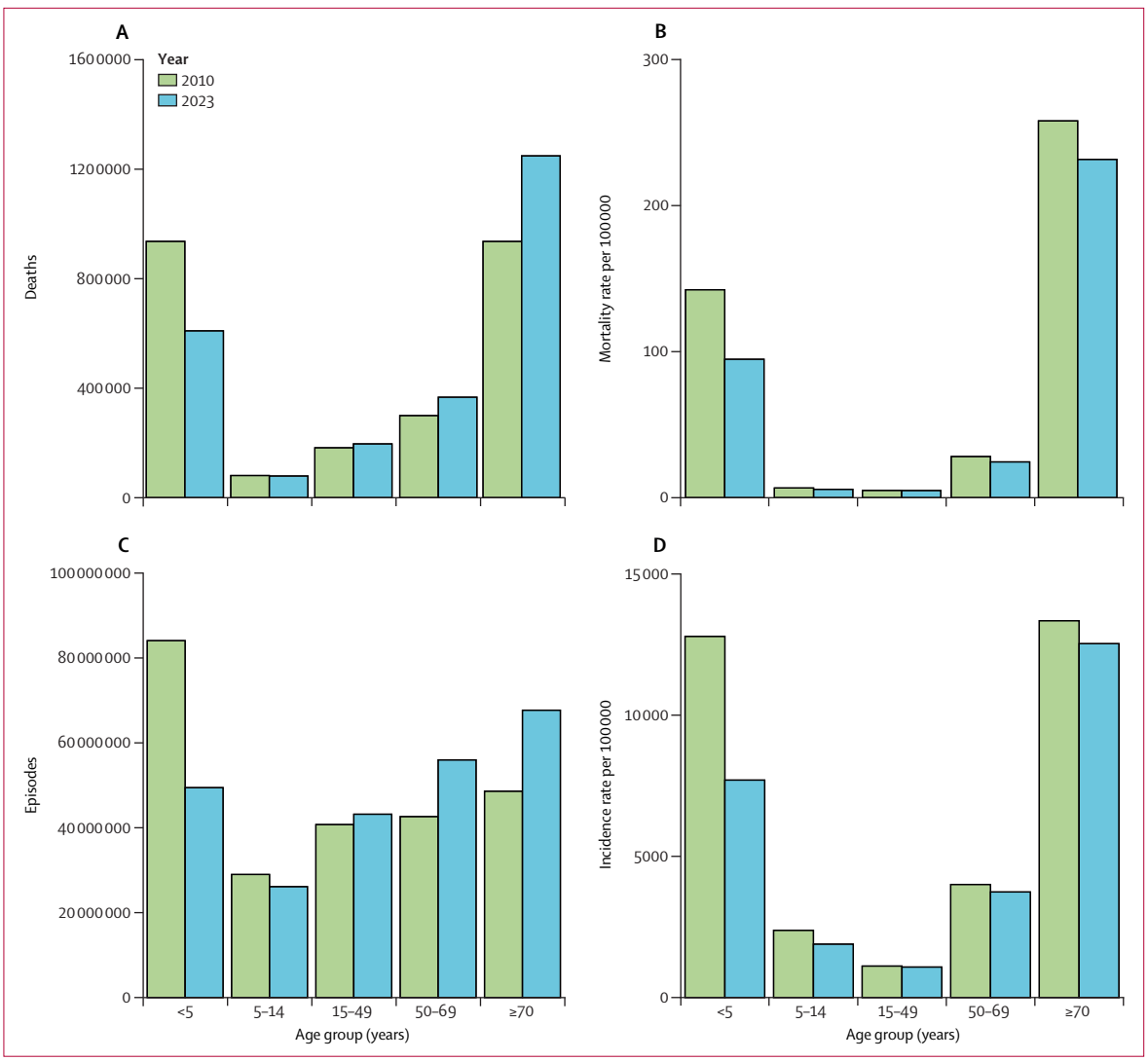


*Figure 2:* **LRI deaths (A), mortality rates (B), episodes (C), and incidence rates (D) by age group in 2010 and 2023**
LRI=lower respiratory infection.

12·3 million (10·7–13·7) global DALYs and a DALY rate of 3400·4 (2943·7–3780·7) per 100 000 (table 2).

Across all ages, the global LRI DALY count in males was 53·6 million (45·2–65·4), with a rate of 1324·9 (1115·8–1616·2) per 100 000 in 2023 (appendix 2 table S4). Females had a lower burden compared to males, at 45·1 million (37·5–54·3) DALYs, with a rate of 1122·0 (933·2–1352·5) per 100 000 (appendix 2 table S4). The location with the highest all-age rate of LRI DALYs in 2023 was Niger (8961·6 [6615·9–12 083·4] per 100 000), followed by the Central African Republic (7512·6 [5412·0–10 125·6] per 100 000) and Chad (7134·7 [5029·5–9626·9] per 100 000; appendix 2 table S4).

## Aetiology results

Globally, the pathogen responsible for the most all-age deaths in 2023 was *S pneumoniae* (634 000 [95% UI 565 000–721 000]), followed by *S aureus* (271 000 [243 000–298 000]) and *K pneumoniae* (228 000 [204 000–261 000]; appendix 2 figure S1, table S5, figure S3A). Globally, *S pneumoniae* was responsible for 25·3% (24·5–26·1) of deaths due to LRIs in 2023, *S aureus* for 10·9% (10·3–11·3), and *K pneumoniae* for 9·1% (8·8–9·5; appendix 2 table S6). In 2010, *S pneumoniae* was also the leading cause of death (876 000 [771 000–984 000]), followed by *S aureus* (271 000 [243 000–298 000]) and *K pneumoniae* (228 000 [204 000–261 000]; appendix 2 figure S1).

Among children younger than 5 years, the pathogen responsible for the largest mortality in 2023 was *S pneumoniae*, responsible for 197 000 (153 000–244 000) deaths (appendix 2 figure S1), equivalent to a rate of 30·6 (95% UI 23·8–38·0) deaths per 100 000 (figure 4). This is a decline from 64·8 (52·4–79·9) deaths per 100 000 in

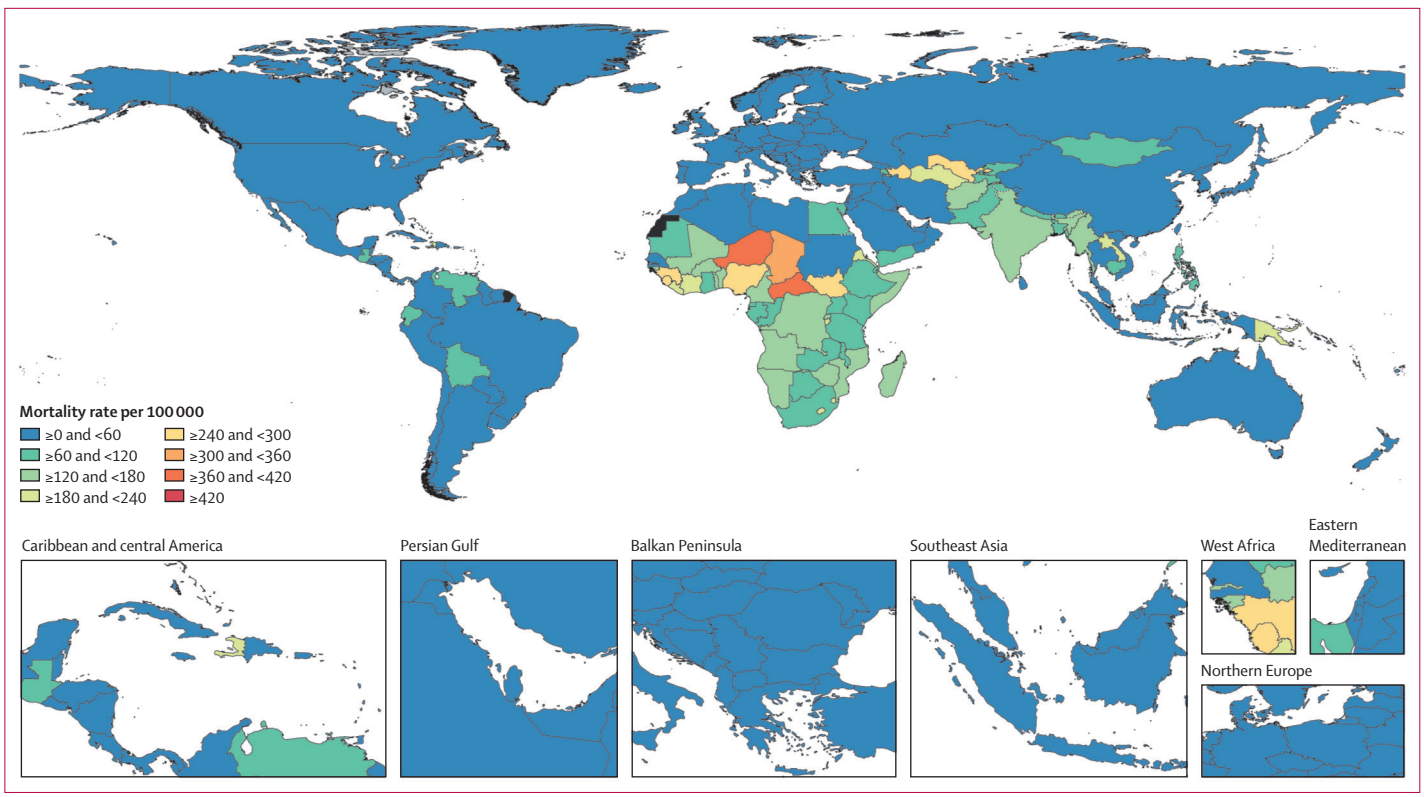


***Figure 3:*** **LRI mortality rate per 100 000 in children younger than 5 years in 2023**
LRI=lower respiratory infection.

2010, when it was also the leading pathogen in this age group (figure 4). In adults aged 70 years or older, *S pneumoniae* caused the highest mortality rate in both 2023 (50·4 [43·3–58·5] per 100 000) and 2010 (71·0 [60·7–79·6] per 100 000; figure 4; appendix 2 figure S4). In 2023, this comprised 272 000 (234 000–316 000) deaths for this pathogen and age group (figure 4).

The leading pathogen in LRI incident episodes in 2023 was *S pneumoniae*, accounting for 58·3 million (95% UI 54·7–63·2) episodes, followed by influenza (22·5 million [19·6–26·5] episodes) and *Mycoplasma* spp (17·1 million [15·8–18·4] episodes; appendix 2 figure S1, table S7, figure S3B). Globally, *S pneumoniae* was responsible for 24·2% (23·5–24·9) of incident episodes in 2023 (appendix 2 table S6). In 2010, the largest number of incident episodes came from *S pneumoniae* (73·9 million [68·9–80·3] episodes), followed by influenza (31·9 million [30·0–34·1] episodes; appendix 2 figure S1). Among children younger than 5 years, *S pneumoniae* was the pathogen with the highest incidence rate in both 2023 (2297·3 [95% UI 1994·6–2660·6] per 100 000) and 2010 (4776·9 [4150·7–5409·8] per 100 000), followed by RSV with an incidence rate of 1187·5 (972·0–1433·6) per 100 000 in 2023 and 2808·8 (2441·3–3182·5) per 100 000 in 2010 (figure 4; appendix 2 figure S4). Similarly, in adults aged 70 years and older, *S pneumoniae* was the pathogen with the largest incidence rate in 2023 (2416·1 [2211·6–2631·1] per 100 000), as well as in 2010 (2767·3 [2545·2–3001·8] per 100 000; figure 4; appendix 2 figure S4), followed by influenza with an incidence rate of 1530·2 (1315·2–1867·0) per 100 000 in 2023 and 2622·7 (2415·2–2851·7) per 100 000 in 2010.

In the high-income super-region, *S aureus* caused the highest proportion of mortality across all ages in 2023, responsible for an estimated 18·8% (95% UI 18·3–19·3) of deaths (appendix 2 table S6). In all other super-regions, *S pneumoniae* was responsible for the highest all-age mortality proportion: central Europe, eastern Europe, and central Asia (23·0% [22·6–23·5]); south Asia (30·7% [29·5–31·7]); Latin America and the Caribbean (19·4% [18·9–19·9]); north Africa and the Middle East (24·0% [22·5–25·4]); southeast Asia, east Asia, and Oceania (29·1% [28·6–29·5]); and sub-Saharan Africa (27·9% [26·3–29·3]; appendix 2 table S6). In the high-income super-region, *S pneumoniae* caused 14·1% (13·7–4·5) of deaths.

The 11 newly modelled pathogens in GBD 2023 accounted for approximately 22% of LRI deaths (appendix 2 figure S1). Of the new pathogens modelled in GBD 2023, other *Mycobacterium* species (non-tuberculosis, non-leprosy) were responsible for the largest number of deaths (177 000 [95% UI 155 000–201 000]) followed by other Gram-negative bacteria (72 400 [63 700–82 600]) and *Aspergillus* spp (67 800 [59 900–75 900]; appendix 2

| | 2010 | | 2023 | | Percentage change in DALY rates between 2010 and 2023 |
|---|---|---|---|---|---|
| | DALYs | DALY rate per 100 000 | DALYs | DALY rate per 100 000 | |
| All ages | 122 000 000 (106 000 000 to 140 000 000) | 1747·0 (1524·1 to 2005·1) | 98 700 000 (87 700 000 to 112 000 000) | 1223·8 (1087·9 to 1388·8) | –29·9% (–40·6 to –14·9) |
| <5 years | 83 500 000 (68 200 000 to 100 000 000) | 12 697·9 (10 373·1 to 15 274·5) | 54 400 000 (43 400 000 to 66 800 000) | 8454·8 (6748·8 to 10 381·7) | –33·4% (–47·3 to –10·4) |
| 5–14 years | 6 620 000 (5 300 000 to 8 350 000) | 542·9 (434·1 to 684·6) | 6 460 000 (5 120 000 to 8 260 000) | 466·9 (370·0 to 597·6) | –14·0% (–36·7 to 20·4) |
| 15–49 years | 10 200 000 (8 630 000 to 11 900 000) | 279·3 (236·0 to 325·9) | 11 000 000 (9 060 000 to 13 500 000) | 274·3 (226·4 to 338·4) | –1·8% (–22·0 to 29·8) |
| 50–69 years | 8 960 000 (7 770 000 to 10 300 000) | 841·8 (730·0 to 963·2) | 10 900 000 (9 390 000 to 12 700 000) | 726·0 (627·3 to 849·1) | –13·7% (–28·3 to 9·5) |
| ≥70 years | 12 300 000 (10 700 000 to 13 700 000) | 3400·4 (2943·7 to 3780·7) | 16 000 000 (13 900 000 to 18 300 000) | 2974·8 (2580·0 to 3390·6) | –12·5% (–24·9 to 1·5) |

Data in parentheses are 95% uncertainty intervals. Count data are presented to three significant figures, and rates and percentages are presented to one decimal place. 2010 estimates are included alongside 2023 estimates because the GAPPD goals, published in 2013, use a baseline year of 2010; this presentation facilitates comparison to GAPPD benchmarks. GAPPD=Global Action Plan for Prevention and Control of Pneumonia and Diarrhoea.

***Table 2:*** **DALY estimates of lower respiratory infection globally by age in 2010 and 2023**

figure S1, table S5). Southern Latin America was the region with the highest proportion of LRI deaths attributable to other *Mycobacterium* species, at 9·5% (9·2–9·7), alongside tropical Latin America (9·5% [8·8–10·0]; appendix 2 table S6).

Of the newly modelled pathogens, other fungi were responsible for the largest number of global incident episodes (15·7 million [95% UI 14·6–16·7]) followed by other *Mycobacterium* species (non-tuberculosis, non-leprosy; 6·19 million [5·77–6·59]) and other Gram-negative bacteria (5·53 million [5·17–5·91]; appendix 2 figure S1, table S7).

## Discussion

This study presents estimates of the global LRI burden attributable to 26 pathogen categories by age group and sex, with 11 categories modelled for the first time, providing a deeper understanding of the current landscape of pathogenic causes of LRIs and insights that could inform the future development of mitigation strategies. We found that despite substantial progress, LRIs still pose a considerable disease burden in children younger than 5 years. In 2023, 610 000 (95% UI 486 000–749 000) deaths in this age group were attributed to LRIs, representing 13·1% (10·5–16·1) of all under-5 mortality (GBD Compare). Many countries and territories are not on track to meet the GAPPD target for 2025 of fewer than three pneumonia deaths per 1000 livebirths among children younger than 5 years,[14] which is roughly equivalent to a mortality rate of less than 60 deaths per 100 000 people per year in this age group. As of 2023, we estimated a global LRI mortality rate of 94·8 (75·6–116·4) deaths per 100 000 children younger than 5 years, down from 142·4 (116·3–171·5) deaths per 100 000 in 2010. GAPPD also targeted a 75% reduction in the incidence of severe pneumonia from 2010 to 2025 among children younger than 5 years. Although the current study did not model severe pneumonia as an outcome, we estimated a 39·8% (37·8–41·5) decrease in the LRI incidence rate and a 33·4% (10·4–47·4) decrease in the LRI mortality rate from 2010 to 2023 in this age group (appendix 2 table S1). Achieving rates low enough to meet the GAPPD targets will require sustained, targeted efforts in locations with the highest burden, including further scale-up of proven interventions, such as expanding vaccination coverage and improving access to health care.

Vaccinations against *S pneumoniae* and *H influenzae* type b have been particularly effective in reducing mortality due to LRIs among children, averting an estimated 1·76 million childhood deaths in the past two decades.[22] Seasonal vaccinations against influenza, although not as effective or as widespread as these childhood bacterial vaccines, still play a key role in averting mortality.[23,24] New RSV long-acting monoclonal antibodies and RSV vaccines are promising interventions to prevent mortality due to RSV in both young children and adults, with several already approved and 30 additional RSV vaccine candidates still in development.[25] However, as of the 2024–25 respiratory infection season,[26] the newest RSV monoclonal antibodies and vaccines were still unavailable in low-income countries, where the LRI burden is highest. Global roll-out of an RSV vaccine with 60% efficacy could have averted 123 700–177 700 deaths in Gavi-eligible countries from 2023 to 2025.[27] Ensuring equitable access is therefore crucial for the impactful deployment of new anti-LRI interventions.

We found that adults aged 70 years and older were still at a greater risk of death due to LRIs than any other age group in 2023. Despite the progress in *S pneumoniae* mortality in adults aged 70 years and older—from a mortality rate of 71·0 (60·7–79·6) per 100 000 in 2010 to 50·4 (43·3–58·5) per 100 000 in 2023—this pathogen

For more on the **GBD Compare** see https://vizhub.healthdata.org/gbd-compare/

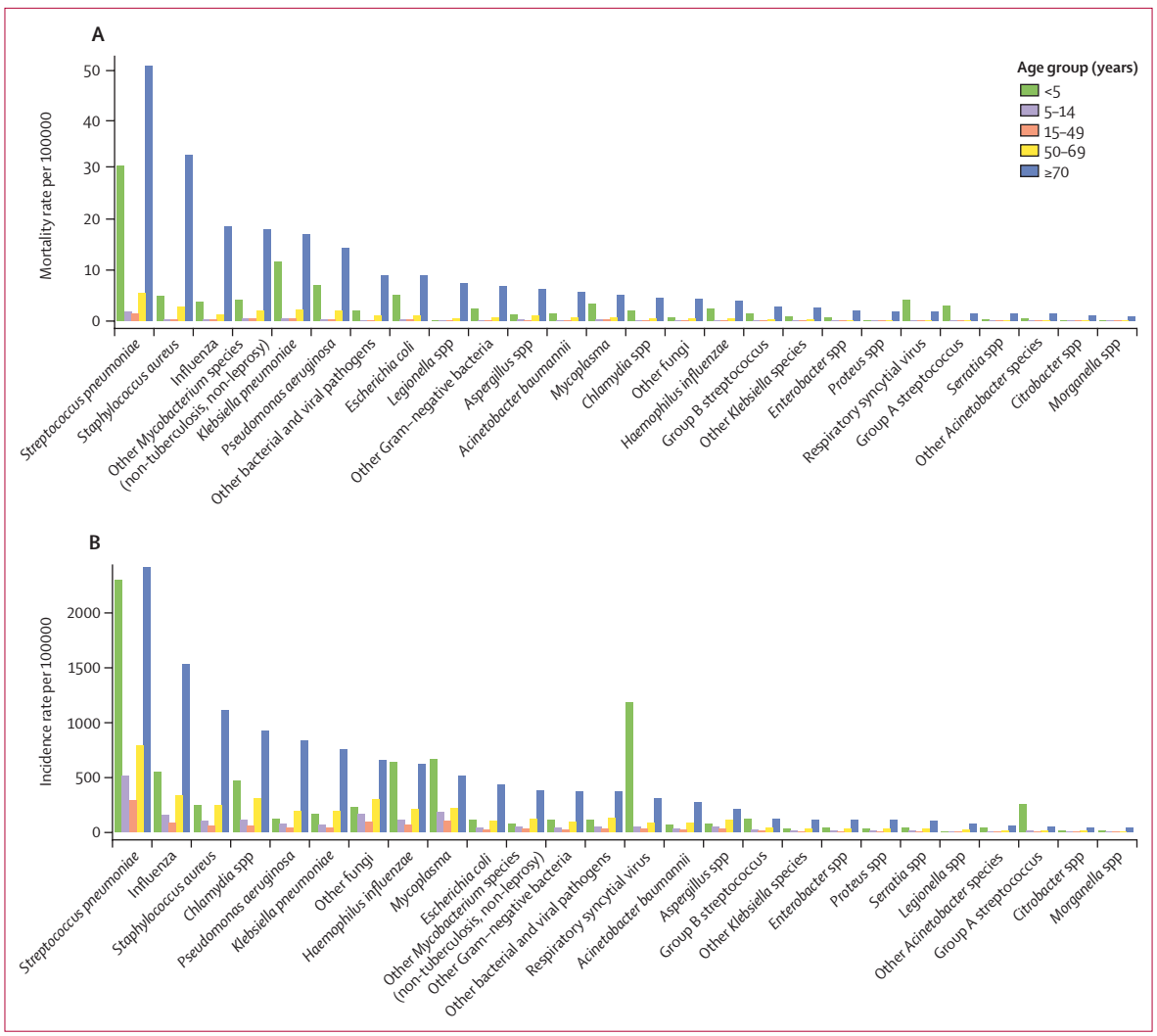


***Figure 4:*** **LRI mortality rate (A) and incidence rate (B) by aetiology in 2023**
LRI=lower respiratory infection.

alone was responsible for 272 000 (95% UI 234 000–316 000) LRI deaths in this age group in 2023. In low-income and middle-income countries (LMICs) especially, adult pneumococcal vaccines are underused despite a substantial burden of disease among older adults and high-risk populations, partly because the body of evidence for adult vaccination is highly concentrated in high-income settings.[28,29] Available evidence indicates that both 23-valent PPSV and 13-valent PCV are cost-effective or cost-saving for adults older than 50 years in LMICs.[29,30] Similarly, recent research has shown that the influenza vaccine is cost effective for older adults—in particular, the high-dose influenza vaccine is cost-effective in high-income countries—but evidence is restricted in LMICs.[31–33] Where adult vaccination in LMICs is recommended, it is typically limited to high-risk groups, and coverage rates remain low due to barriers such as low awareness, inconsistent recommendations, high cost, complex access pathways, and the absence of a coordinated governmental programme.[29] The optimal age for adult vaccination in LMICs might be earlier than in high-income countries, and might vary by country depending on the age distribution and disease burden.[34] There is also a need for region-specific vaccine strategies due to differences in circulating serotypes and the emergence of non-vaccine types.[35] As the global population continues to age, comprehensive vaccination strategies are crucial for reduction of LRI deaths.[16]

*S pneumoniae* was the leading pathogen responsible for most of the mortality due to LRIs worldwide in 2023. It was also the leading cause of LRI incident episodes in the same year, followed by influenza. Our newly modelled pathogens, although individually rare, comprised more than 500 000 LRI deaths globally in 2023. Mitigation of these pathogens will require broader pathogen surveillance and tailored public health strategies beyond

the most common causes of LRIs. Next-generation sequencing (NGS) for pathogen detection is highly sensitive, with one study in a single community hospital in eastern China reporting identification of a pathogen in 84·5% of LRI cases, which was significantly higher than the 26·8% identified with traditional methods.[36] However, NGS remains prohibitively expensive in many settings, and it can be prone to false-positive results.[37] Multiplex PCR, which is less expensive than NGS but also more sensitive than culture, is widely available commercially, even in some low-income and middle-income settings.[38,39] Additionally, some commercial PCR technologies allow for the identification of common antimicrobial resistance genes, enabling personalised tailoring of antibiotic therapy. These technologies have led to increased detection rates, more accurate pathogen identification, and enhanced surveillance quality, supporting better antimicrobial stewardship and public health response.[40] Collection, interpretation, and worldwide sharing of data—through international organisations such as the WHO International Pathogen Surveillance Network—can provide further information to guide policy.

For more on the **WHO International Pathogen Surveillance Network** see https://www.who.int/initiatives/international-pathogen-surveillance-network

We estimated 67 800 (95% UI 59 900–75 900) LRI deaths attributable to *Aspergillus* spp in 2023 (appendix 2 table S5). A 2024 review by Denning estimated the global mortality due to invasive pulmonary aspergillosis at 1·8 million annual deaths, of which 1·3 million were directly attributable to *Aspergillus* spp.[41] These estimates differ in part because of the mutually exclusive nature of GBD death attribution, as some deaths involving *Aspergillus* spp are attributed to an underlying cause such as chronic obstructive pulmonary disease or cancer, when such information is available in the data. Furthermore, the current study used a composite of multiple sources to model CFRs by location and year, whereas Denning's review utilised a single, anti-conservative estimate for CFR to convert cases to deaths, leading to the possibility of overestimation of mortality.[41,42] Unfortunately, pulmonary aspergillosis remains difficult to diagnose; sputum cultures are only approximately 35% sensitive, and fungal cultures can take 48–72 h to grow.[43,44] More sensitive diagnostic tests, such as galactomannan antigen and PCR, can assist clinicians in making a more rapid diagnosis.

Our work adds to a growing body of research highlighting the rising burden of other *Mycobacterium* species (non-tuberculosis, non-leprosy), also known as non-tuberculous mycobacteria (NTM), in pulmonary infections. We estimate that NTM represents the most common of the newly modelled aetiologies, ranking twelfth in LRI cases and fourth in LRI deaths (appendix 2 figure S3A, S3B). Although our study is the first to estimate NTM incidence comprehensively, several recent reviews have discussed the increasing incidence of NTM. One 2022 global systematic review estimated a 4% year-over-year increase in NTM pulmonary infections, driven mainly by *Mycobacterium avium*.[13] Another 2023 systematic review, which characterised the detection of NTM in multiple world regions, observed an increasing incidence of NTM in east Asia; in Japan, NTM pulmonary infection incidence now exceeds tuberculosis incidence.[45] Studies in patients with suspected tuberculosis in Kenya, Nigeria, and Uganda found that between 4·2% and 15% of mycobacteria-positive patients had an NTM pathogen.[46–48] A similar study in northern Brazil found that 13·5% of mycobacteria-positive specimens contained an NTM pathogen.[49] This work emphasises the importance of accurate and comprehensive diagnostic capacities, not only to guide epidemiological priorities but also to ensure prompt and accurate treatment for patients with all mycobacterial infections.

Furthermore, we highlight the high global incidence of *M pneumoniae,* the third-leading cause of global LRI episodes, which is not preventable by vaccination. Although *M pneumoniae* classically presents as a mild illness in young and healthy patients, severe cases do occur and could be associated with antimicrobial resistance. There has been a surge in macrolide-resistant *M pneumoniae* in certain locations; for example, estimated resistance proportions have exceeded 50% in the Western Pacific and have reached more than 90% in a recent study in China.[50–52] Increasing resistance patterns are associated with a corresponding increase in severe and refractory pneumonia presentations among children and adults.[50–52] In these settings, empirical use of non-macrolide agents, such as tetracyclines or fluroquinolones, is increasingly necessary to reduce the risk of treatment failure and adverse outcomes.

This study has made several improvements compared to GBD 2021. For example, in GBD 2021, when cause of death data for the pandemic years were largely unavailable, we applied a scalar based on the estimated reduction in influenza and RSV during the COVID-19 pandemic to the LRI mortality envelope to account for the impact of the pandemic. By contrast, in GBD 2023, we included empirical cause of death data to inform the LRI mortality estimates for recent years, including the pandemic years of 2020 and 2021. Additionally, in areas with scarce data and large populations, the inclusion of low-quality data with small sample sizes can lead to substantial shifts in model estimates. In the current study, we excluded data from hospitals in India with small sample sizes, which exhibit systematic bias and are unlikely to reflect values representative of the wider population. Furthermore, our updated pathogen distribution analysis includes more than twice as many isolates as were analysed in the previous round of the study (12·7 million compared to 6·1 million). In addition to including updated years and pathogens from many previously used data sources, we incorporated 21 new data sources and data encompassing 20 countries that previously did not have data.

This study has several limitations. First, as with all GBD publications, we are limited by the availability of data. Results for locations without data—which are often low-income, high-burden areas—are estimated using covariates and data from neighbouring locations. Second, we did not include all possible covariates; for example, we did not model population coverage of the influenza vaccine, or of new RSV vaccines or monoclonal antibodies; these might be added in future GBD rounds. Third, our pathogen distribution model attributes cases and deaths found to have both a virus and a bacterial pathogen to the bacterial pathogen only; this approach can underestimate the contribution of viruses at an aggregate level. Fourth, although our analysis does not directly account for the impact of lifting of non-pharmaceutical interventions (NPIs) on influenza, we observed a notable increase in the ranking of influenza in 2023. This increase might be partly attributed to the relaxation of NPI policies following the pandemic. By contrast, the reductions in influenza observed during the pandemic years coincided with widespread implementation of NPIs.[4,53,54] Fifth, we directly applied LRI aetiology proportions from our pathogen distribution models to our overall estimates of LRI cases and deaths, even though the two methodologies have slightly different definitions of LRI. More specifically, for fatal cases, the GBD definition of LRI only includes instances in which LRI was the underlying cause of death, whereas the pathogen distribution model definition includes any instance where LRI was present in the causal chain, irrespective of the underlying cause of death. Sixth, our current pathogen estimation method relies on a global model with country-level covariates, rather than separate regional or country-specific models. Although this allows us to build a robust set of estimates that characterises the LRI proportions of 25 pathogens, many of which are not widely studied in LMICs, it cannot fully capture the local endemicity of pathogens and might underestimate differences across geographical regions.

In summary, LRIs remain a leading cause of infectious morbidity and mortality, particularly in children younger than 5 years and older adults. Although substantial progress has been made, current rates of LRI mortality in children younger than 5 years still exceed the GAPPD mortality target. Achieving further reductions will require sustained investment in proven interventions, equitable access to vaccines, and tailored strategies for high-burden populations. Enhanced surveillance, diagnostics, and data sharing are essential for guiding public health responses and monitoring progress. Addressing gaps in adult vaccination, tackling non-vaccine-preventable pathogens, and controlling antimicrobial resistance are also crucial to reducing the LRI burden. Overall, global attention to evidence-based and affordable interventions remains vital for progress against LRIs.

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See Online for appendix 3

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Please see appendix 3 (pp 40–53) for more detailed information about individual author contributions to the research, divided into the following categories: managing the overall research enterprise; writing the first draft of the manuscript; primary responsibility for applying analytical methods to produce estimates; primary responsibility for seeking, cataloguing, extracting, or cleaning data; designing or coding figures and tables; providing data or critical feedback on data sources; developing methods or computational machinery; providing critical feedback on methods or results; drafting the manuscript or revising it critically for important intellectual content; and managing the estimation or publications process.

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### Data sharing

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