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# Global, regional and national burden of pertussis in 1990–2023: a Global Burden of Disease study

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Despite long-standing immunization programs, pertussis remains a major cause of vaccine-preventable mortality, particularly among infants. Here we present a primary assessment of global pertussis incidence, mortality and disability-adjusted life years across 204 countries and territories from 1990 to 2023. We show that despite short-term pandemic-period fluctuations, the dominant global pattern from 1990 to 2023 was long-term decline: age-standardized mortality decreased by 61.2% and age-standardized incidence by 41.6%. Relative to the anomalously low pandemic-period estimates, incidence and mortality rebounded by 102.6% (95% uncertainty interval, 77.0–128.2%) and 66.1% (95% uncertainty interval, 2.4–174.5%), respectively, between 2020 and 2023. In 2023 alone, we estimated 18.9 million cases and 115,000 deaths attributable to pertussis. This burden remains profoundly inequitable and inversely correlated with the sociodemographic index; sub-Saharan Africa now accounts for roughly 65% of global deaths, with the highest population-adjusted risk concentrated among infants younger than 6 months. Our findings highlight a modeled geographic concentration of pertussis mortality and support strengthening timely infant vaccination, maternal immunization where recommended and feasible and robust surveillance in highly susceptible regions.

*Bordetella pertussis*, the causative agent of pertussis (whooping cough), is a highly contagious respiratory bacterial pathogen with important global health implications. Before the introduction of effective vaccines, pertussis was a leading cause of childhood mortality worldwide, responsible for hundreds of thousands of deaths annually, particularly among infants and young children[1–4]. Despite the widespread implementation of vaccination programs, pertussis continues to be one of the most important causes of vaccine-preventable deaths in children. While a previous study[1] reported 24.1 million cases and 160,700 deaths in children under 5 years of age as of 2014, the burden remains disproportionately concentrated in low- and middle-income countries[2,5,6]. The disease poses a severe threat especially to infants, who are not only too young to be fully vaccinated, but also physiologically more vulnerable to severe and life-threatening complications[7,8].

Since the advent of whole-cell pertussis vaccines in the 1940s and the global expansion of immunization programs in the 1970s, there has been a dramatic reduction in pertussis-related mortality and morbidity[1–4]. However, persistent transmission remains a challenge. In recent decades, several high-income countries have experienced a resurgence or plateauing of pertussis incidence, while low-income regions continue to bear a disproportionate burden of disease[2,5,6,9–12]. In some well-resourced settings, external evidence suggests that waning immunity after acellular pertussis vaccination, differences between whole-cell pertussis and acellular pertussis vaccine-induced

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protection, and changes in surveillance and diagnostic intensity may contribute to persistent or recurrent pertussis incidence[9,11,13–16]. Furthermore, recent evidence highlights pathogen adaptation—such as the emergence of pertactin-deficient and macrolide-resistant *B. pertussis* strains—which may further undermine vaccine-induced protection[17–21]. Conversely, in settings with a low sociodemographic index (SDI), incomplete vaccine coverage, limited surveillance capacity and structural inequities in healthcare access remain the primary barriers to control[10–12,22–25].

These existing challenges were profoundly compounded by the coronavirus disease 2019 (COVID-19) pandemic, which created unprecedented disruptions to routine immunization services and surveillance systems[9,26,27]. During the acute pandemic phase, changes in contact patterns, mitigation measures, healthcare seeking, diagnostic testing and reporting systems coincided with marked reductions in detected respiratory infections, including pertussis[28]. Decreased third-dose diphtheria–tetanus–pertussis (DTP3) vaccine coverage and reduced natural immune boosting may also have increased population susceptibility, although their relative contributions cannot be separated in the present analysis[9,29]. As pandemic restrictions eased, this accumulation of susceptible individuals was associated with a rebound in reported pertussis activity in multiple regions[28]. Previous global studies, including earlier iterations of the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD)[30], have provided valuable epidemiologic insights but could not fully capture pandemic-period suppression and the early post-pandemic rebound now observed through 2023 (ref. 31).

This study used GBD 2023 estimates to assess pertussis incidence, mortality and disability-adjusted life years (DALYs) from 1990 to 2023 across 204 countries and territories. We aimed to characterize long-term and pandemic-period temporal trends, geographic and sociodemographic inequalities, and age-specific and sex-specific patterns in disease burden, with particular attention to the burden among young infants.

## Results

### Global and regional temporal trends

Between 1990 and 2023, the dominant global pattern was a substantial long-term decline in pertussis burden. The global age-standardized mortality rate (ASMR) decreased from 4.61 per 100,000 in 1990 to 1.79 per 100,000 in 2023, representing a 61.2% reduction. The global age-standardized incidence rate (ASIR) also declined by 41.6% over the same period. In 2023, GBD estimated 18,955,648 incident cases (95% uncertainty interval (UI), 14,956,386–24,270,133) and 115,242 deaths (95% UI, 66,577–189,183). To contextualize the post-pandemic period, we compared 2023 estimates directly with the 2019 pre-pandemic baseline. The global ASIR in 2023 was 293.7 per 100,000 (95% UI 231.8–376.1), broadly comparable to 286.4 per 100,000 (95% UI 226.0–366.5) in 2019. Similarly, the global ASMR in 2023 was 1.79 per 100,000 (95% UI 1.03–2.94), slightly below the 2019 estimate of 1.88 per 100,000 (95% UI 1.09–3.05). These comparisons indicate a return toward pre-pandemic baseline levels rather than an unprecedented global surge by 2023. Relative to the anomalously low pandemic-period estimates, incidence increased by 102.6% (95% UI 77.0–128.2%) and mortality by 66.1% (95% UI 2.4–174.5%) between 2020 and 2023 (Fig. 1a–c and Table 1).

Regionally, East Asia achieved the largest reductions, with ASMRs and ASIRs declining by 91.2% (95% UI 35.0–98.3%) and 60.3% (95% UI 57.1–62.8%), respectively. Tropical Latin America also showed a reduction, with a 70.7% (95% UI 10.9–95.2%) decline in ASMRs. In contrast, Oceania experienced the largest increases in absolute numbers—deaths and cases rose by 57.8% and 116.2%, respectively—although its ASMR exhibited a nonsignificant change (−20.5%, 95% UI −87.0% to 295.9%). The wide UIs observed in regions such as Oceania are indicative of data scarcity in smaller populations. Similarly, trends in Southern sub-Saharan Africa showed stagnation, with a nonsignificant change in ASMR (−12.5%, 95% UI −77.6% to 188.8%; Supplementary Tables 2–6). At the country level, 36 (17.6%) of 204 countries showed an increased incidence pattern from 1990 to 2023. For example, the incidence rate in the United States increased from 48.8 (95% UI 36.6 to 63.4) per 100,000 in 1990 to 126.7 (95% UI 98.4 to 161.1) per 100,000 in 2023, with ASIR rising by 158.6% (95% UI 139.6–178.8; Supplementary Table 7).

In a descriptive comparison with public World Health Organization (WHO)/United Nations Children's Fund (UNICEF) JRF surveillance data, 200 of 204 GBD country or territory locations were matched to WHO/JRF country codes, and 2023 reported incidence data were available for 162 matched locations (Supplementary Table 8 and Extended Data Fig. 1a). Country-level concordance in all-age incidence rates was limited (Pearson $r = -0.103$; Spearman $\rho = -0.180$). Among the 116 locations with positive case counts in both sources, the log-scale Pearson and Spearman correlations were 0.398 and 0.348, respectively (Extended Data Fig. 1b). Across the 166 locations with available WHO/JRF 2024 data, the Spearman correlation between GBD 2023 estimated case ranks and WHO/JRF 2024 notification ranks was 0.314, and China was the only location included in both top-ten lists (Supplementary Table 8). WHO/JRF recorded 163,454 reported cases among matched locations with available data in 2023, whereas GBD 2023 estimated 18.9 million cases across all 204 locations. These quantities are not directly comparable because WHO/JRF data represent reported cases, whereas GBD estimates aim to approximate underlying incidence after modeling and adjustment for incomplete ascertainment. In the WHO public summary, reported cases increased globally from 163,388 in 2023 to 941,582 in 2024 (5.76-fold), with the largest regional increase in the Western Pacific region, from 49,406 to 593,659 cases (12.0-fold; Supplementary Table 9 and Extended Data Fig. 1c). China had the largest reported national increase, from 41,124 cases in 2023 to 476,690 in 2024 (Supplementary Table 8).

### Geographic disparities in burden

In 2023, geographic disparities persisted, characterized by a shift in burden concentration. In the GBD modeled estimates, sub-Saharan Africa had the largest share of global pertussis mortality and DALYs, accounting for 63–65% of global pertussis deaths and DALYs—a substantial increase from its ~30% share in 1990. This growing proportional share primarily reflects slower rates of decline compared to other regions, rather than an absolute increase in regional mortality. The region recorded an ASMR of 4.18 per 100,000 (95% UI 2.20–7.60) in 2023. At the national level, Nigeria (ASMR 4.99 per 100,000, 95% UI: 0.47–14.23) and the Democratic Republic of the Congo (ASMR 5.19 per 100,000, 95% UI: 0.60–15.53) exemplified this severity. Longitudinal analysis indicates that estimated mortality reductions in these countries between 1990 and 2023 (−49.2% and −51.5%, respectively) were not statistically significant, with wide UIs crossing zero (Fig. 2).

South Asia, which dominated the global burden in 1990 with approximately 38% of deaths and DALYs, saw its share decline to approximately 17% for deaths and DALYs, while accounting for 21% of global incidence by 2023. The region recorded an estimated 3.91 million cases and 19,852 deaths in 2023. India achieved a significant 85.1% (95% UI 33.2–98.2%) reduction in ASMR. However, heterogeneity exists; Pakistan showed a nonsignificant mortality reduction of 68.3% (95% UI −222.7% to 96.1%). For incidence, the shift in contribution was more moderate than for mortality: South Asia (20.6%) and Western sub-Saharan Africa (20.3%) showed comparable contributions to the global case count in 2023.

By comparison, East Asia and Central Asia maintained extremely low burdens; for instance, China had an estimated ASMR of 0.13 per 100,000 following a 92.4% decline, and Kyrgyzstan achieved a near-total reduction (−99.9%). High-income regions maintained consistently minimal burdens, contributing less than 5% to global deaths throughout the study period (Fig. 1d–f).

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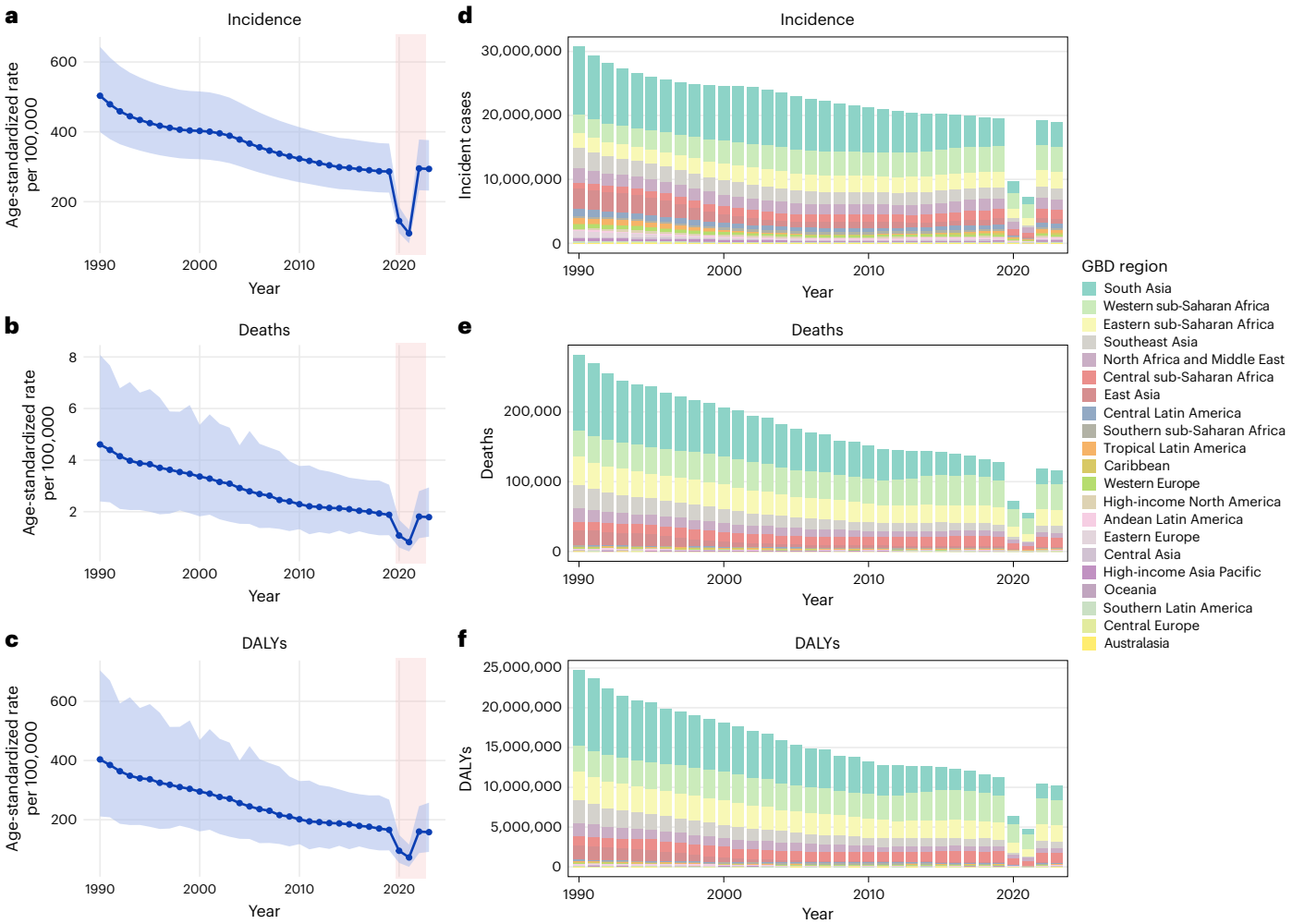



**Fig. 1 | Global trends and regional distribution of pertussis incidence, deaths and DALYs, 1990–2023. a**, Global ASIR per 100,000 population. **b**, Global ASMR per 100,000 population. **c**, Global ASDR per 100,000 population. Solid lines show GBD 2023 point estimates, defined as the means of 1,000 draws; blue shaded areas show 95% UIs, defined by the 2.5th and 97.5th percentiles of the draws. The pink vertical band indicates 2019–2022, the period spanning the COVID-19 pandemic and associated disruption to routine services and surveillance. **d**, Absolute number of incident cases by GBD region. **e**, Absolute number of deaths by GBD region. **f**, Absolute number of DALYs by GBD region. Stacked-bar heights show GBD 2023 point estimates (means of 1,000 draws) for all ages and both sexes; colors indicate the contribution of each GBD region.

## Age-specific and sex-specific patterns of burden

Age remains a major determinant of risk, with the highest population-adjusted mortality rates consistently observed in early infancy. In 2023, the distribution of pertussis burden varied depending on whether absolute numbers or population-adjusted rates were examined, highlighting the crucial distinction between the aggregate number of fatalities within an age cohort and the actual individual risk of death. While the highest absolute number of deaths occurred in children aged 2–4 years (25,954, 95% UI 14,786–43,587), the risk of death was highest in early infancy. The mortality rate for infants aged 1–5 months was 45.7 per 100,000 (95% UI 26.0–79.0)—more than double that of the 12–23-month group (19.6) and nearly triple that of the 2–4-year group (6.61). This intense risk concentration in early infancy represents a marked improvement from 1990, when mortality rates in the 1–5-month group were 108.1 per 100,000. Incidence rates followed a similar age-dependent gradient, peaking in the 1–5-month group. Notably, sex differences in both mortality and incidence rates were minimal, with largely overlapping 95% UIs between females and males across all age groups, indicating that age—rather than sex—is the primary determinant of pertussis risk (Fig. 3).

Temporal improvements in pertussis burden varied markedly by region (Extended Data Figs. 2–8). For mortality, high-income regions achieved the steepest declines, with rates in the vulnerable 1–5-month age group dropping by 93.7% (95% UI 76.8–97.7%) to near-elimination levels of 0.20 per 100,000 (95% UI 0.11–0.33). South Asia also achieved rapid declines, with rates falling by 77.3% (95% UI 0.5–94.8%) to 36.8 per 100,000. In contrast, sub-Saharan Africa showed the slowest progress; although the mortality rate in this age group declined by 58.1% (95% UI 19.9–76.6%), it remained exceptionally high at 92.1 per 100,000 (95% UI 50.7–157.3) in 2023.

Unlike the stark disparities in mortality, reductions in incidence rates were less disparate. High-income regions saw declines of approximately 39–42% across childhood age groups, similar to global averages. Furthermore, despite regional differences in magnitude, the relative age profile remained consistent: infants under 6 months consistently faced the highest population-adjusted risk across all regions and time periods.

A post hoc comparison of recent age-specific mortality patterns showed that the global mortality rate among infants aged 1–5 months was similar in 2019 and 2023 (45.47 and 45.73 per 100,000, respectively), with the lowest rate during 2019–2023 occurring in 2021. This suggests that the increase observed from the pandemic-period trough to 2023 primarily reflected rebound from an unusually low

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**Table 1 | Pertussis deaths, incidence and DALYs in 2023 and percentage change from 1990 to 2023, by sex and region**

| Location | Number in 2023 (95% UI) | Changes (%) (95% UI) | ASDR in 2023 (95% UI) | Changes (%) (95% UI) |
|---|---|---|---|---|
| **Incidence** | | | | |
| Global | 18,955,648 (14,956,386 to 24,270,133) | −38.3 (−40.6 to −35.5) | 293.74 (231.80 to 376.09) | −41.6 (−43.7 to −39.0) |
| Female | 10,134,950 (7,997,881 to 12,976,305) | −38.2 (−40.4 to −35.4) | 323.75 (255.52 to 414.51) | −41.5 (−43.6 to −38.9) |
| Male | 8,820,698 (6,958,505 to 11,293,828) | −38.5 (−40.7 to −35.7) | 265.53 (209.50 to 339.97) | −41.8 (−43.9 to −39.2) |
| GBD regions | | | | |
| Central Asia | 156,701 (121,214 to 199,009) | −52.4 (−55.7 to −48) | 153.09 (118.42 to 194.42) | −56.6 (−59.6 to −52.6) |
| Central Europe | 80,546 (62,458 to 102,412) | −37.1 (−38 to −36.2) | 146.74 (113.79 to 186.58) | 6.4 (4.8 to 7.9) |
| Eastern Europe | 127,518 (98,869 to 162,783) | −86 (−86.9 to −84.6) | 138.64 (107.55 to 176.96) | −74.2 (−76 to −71.7) |
| Australasia | 22,888 (17,857 to 29,177) | −33.4 (−36.4 to −29.9) | 123.23 (96.15 to 157.1) | −43.8 (−46.4 to −40.9) |
| High-income Asia Pacific | 34,591 (26,200 to 44,568) | −89.3 (−90.5 to −87.7) | 55.63 (42.13 to 71.67) | −82 (−84.1 to −79.3) |
| High-income North America | 279,744 (218,191 to 356,945) | 87.7 (80.4 to 94.1) | 132.99 (103.72 to 169.69) | 96.3 (88.7 to 103) |
| Southern Latin America | 98,087 (76,724 to 125,063) | −35.7 (−36.7 to −34.6) | 242.94 (190.03 to 309.75) | −18.2 (−19.6 to −16.8) |
| Western Europe | 217,021 (168,430 to 276,573) | −63.3 (−65.4 to −60.6) | 100.22 (77.78 to 127.72) | −60 (−62.3 to −57.1) |
| Andean Latin America | 195,896 (153,447 to 249,614) | −23.1 (−25.2 to −20.6) | 343.37 (268.97 to 437.53) | −28.2 (−30.1 to −25.8) |
| Caribbean | 164,966 (130,475 to 211,495) | −11.7 (−12.3 to −11.2) | 422.12 (333.87 to 541.19) | −6.9 (−7.5 to −6.3) |
| Central Latin America | 718,756 (567,333 to 919,466) | −37.5 (−38.8 to −35.7) | 369.61 (291.74 to 472.82) | −27.2 (−28.8 to −25.2) |
| Tropical Latin America | 606,941 (478,612 to 776,106) | −30.2 (−31.7 to −28.3) | 390.85 (308.21 to 499.78) | −22 (−23.7 to −19.9) |
| North Africa and Middle East | 1,625,999 (1,276,985 to 2,082,050) | −29.8 (−31.7 to −27.7) | 273.17 (214.55 to 349.79) | −39.9 (−41.6 to −38.1) |
| South Asia | 3,907,023 (3,040,224 to 4,985,244) | −63.5 (−66.4 to −59.8) | 242.93 (189.03 to 309.97) | −66.3 (−69 to −62.9) |
| East Asia | 727,813 (564,725 to 928,618) | −76.9 (−78.4 to −75) | 109.82 (85.23 to 140.13) | −60.3 (−62.8 to −57.1) |
| Oceania | 142,868 (111,027 to 183,611) | 116.2 (113.8 to 118.3) | 697.47 (542.05 to 896.37) | 8.4 (7.2 to 9.5) |
| Southeast Asia | 1,821,296 (1,437,259 to 2,330,688) | −43.7 (−45.7 to −41.1) | 331.77 (261.83 to 424.56) | −40.2 (−42.3 to −37.5) |
| Central sub-Saharan Africa | 1,428,240 (1,114,930 to 1,829,246) | 70.3 (67.4 to 73.2) | 632.84 (494.02 to 810.53) | −20.7 (−22 to −19.3) |
| Eastern sub-Saharan Africa | 2,529,254 (2,016,194 to 3,241,527) | 10.3 (6.7 to 14.5) | 381.54 (304.14 to 488.99) | −40.6 (−42.5 to −38.2) |
| Southern sub-Saharan Africa | 214,457 (167,744 to 273,709) | −18.2 (−20.3 to −15.9) | 255.71 (200.01 to 326.35) | −27.5 (−29.3 to −25.4) |
| Western sub-Saharan Africa | 3,855,046 (3,076,374 to 4,944,148) | 38.7 (34 to 44.3) | 467.49 (373.05 to 599.55) | −39.4 (−41.4 to −36.9) |
| **Deaths** | | | | |
| Global | 115,242 (66,577 to 189,183) | −59.1 (−75.1 to −26.2) | 1.79 (1.03 to 2.94) | −61.2 (−76.4 to −29.8) |
| Female | 60,351 (34,893 to 97,391) | −59.1 (−76 to −21.9) | 1.93 (1.11 to 3.11) | −61.2 (−77.3 to −25.9) |
| Male | 54,891 (32,444 to 90,969) | −59.1 (−75.8 to −28.4) | 1.66 (0.98 to 2.75) | −61.1 (−77 to −31.9) |
| GBD regions | | | | |
| Central Asia | 332 (114 to 692) | −60.5 (−88.9 to 58.8) | 0.33 (0.11 to 0.68) | −63.8 (−89.8 to 45) |
| Central Europe | 28 (12 to 50) | −89.3 (−96.3 to −62.1) | 0.05 (0.02 to 0.09) | −82.6 (−93.9 to −38.5) |
| Eastern Europe | 6 (3 to 10) | −83.4 (−91.3 to −67.6) | 0.01 (0.00 to 0.01) | −71.3 (−85.4 to −43.1) |
| Australasia | 0 (0 to 0) | −46.5 (−76.2 to 13) | 0.00 (0.00 to 0.00) | −50.9 (−78.1 to 3.6) |
| High-income Asia Pacific | 9 (2 to 21) | −98.5 (−99.8 to −87) | 0.01 (0.00 to 0.03) | −97.6 (−99.7 to −79.4) |
| High-income North America | 5 (2 to 9) | −32.7 (−71.9 to 55) | 0.00 (0.00 to 0.00) | −28.6 (−70.6 to 65.1) |
| Southern Latin America | 2 (1 to 3) | −95.7 (−97.8 to −91.9) | 0.00 (0.00 to 0.01) | −94 (−96.9 to −88.6) |
| Western Europe | 5 (2 to 9) | −72.9 (−89.5 to −32.7) | 0.00 (0.00 to 0.00) | −69.7 (−88.5 to −24.6) |
| Andean Latin America | 736 (220 to 1,617) | −67.7 (−92.2 to 31.2) | 1.29 (0.39 to 2.83) | −69.8 (−92.7 to 23) |
| Caribbean | 1,462 (261 to 3,531) | −35.3 (−86.1 to 218.8) | 3.74 (0.67 to 9.02) | −32.1 (−85.4 to 234.8) |
| Central Latin America | 161 (77 to 298) | −89 (−95.1 to −75.5) | 0.08 (0.04 to 0.15) | −87 (−94.1 to −71.2) |
| Tropical Latin America | 80 (12 to 209) | −73.3 (−95.6 to −17.8) | 0.05 (0.01 to 0.13) | −70.7 (−95.2 to −10.9) |
| North Africa and Middle East | 6081 (2,669 to 12,048) | −69.2 (−88.1 to −30.8) | 1.02 (0.45 to 2.04) | −73.6 (−89.9 to −40.5) |
| South Asia | 19,852 (5,646 to 44,441) | −81.6 (−95.7 to −19.5) | 1.24 (0.35 to 2.80) | −82.9 (−96 to −25.3) |
| East Asia | 1,064 (212 to 2,521) | −94.7 (−99 to −60.4) | 0.15 (0.03 to 0.36) | −91.2 (−98.3 to −35) |
| Oceania | 749 (132 to 1,966) | 57.8 (−74.1 to 686.2) | 3.70 (0.65 to 9.64) | −20.5 (−87 to 295.9) |
| Southeast Asia | 9,553 (3,882 to 18,756) | −70.8 (−89.7 to −24.2) | 1.74 (0.71 to 3.41) | −68.9 (−89.1 to −19.3) |

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**Table 1 (continued) | Pertussis deaths, incidence and DALYs in 2023 and percentage change from 1990 to 2023, by sex and region**

| Location | Number in 2023 (95% UI) | Changes (%) (95% UI) | ASDR in 2023 (95% UI) | Changes (%) (95% UI) |
|---|---|---|---|---|
| Central sub-Saharan Africa | 13,939 (4,095 to 31,242) | 8.8 (−70.3 to 378.4) | 6.19 (1.81 to 13.97) | −49.7 (−86.3 to 121.1) |
| Eastern sub-Saharan Africa | 23,692 (11,428 to 44,850) | −41.3 (−74.8 to 36.4) | 3.58 (1.73 to 6.77) | −68.7 (−86.6 to −26.8) |
| Southern sub-Saharan Africa | 1,430 (488 to 3,137) | −0.7 (−74.4 to 228.5) | 1.71 (0.58 to 3.74) | −12.5 (−77.6 to 188.8) |
| Western sub-Saharan Africa | 36,057 (13,397 to 80,036) | −5.6 (−63.6 to 164.9) | 4.38 (1.63 to 9.73) | −59.5 (−84.5 to 13.6) |
| **DALY** | | | | |
| Global | 10,130,780 (5,853,398 to 16,503,149) | −59 (−75 to −26.5) | 157.90 (91.16 to 257.53) | −60.9 (−76.2 to −29.8) |
| Female | 5,306,219 (3,082,862 to 8,525,652) | −59 (−75.9 to −22.3) | 170.37 (98.83 to 274.18) | −60.9 (−77.1 to −25.9) |
| Male | 4,824,561 (2,849,348 to 7,920,264) | −59 (−75.6 to −28.8) | 146.17 (86.26 to 240.20) | −60.8 (−76.8 to −31.9) |
| GBD regions | | | | |
| Central Asia | 29,923 (11,018 to 60,957) | −60.4 (−88 to 49.8) | 29.30 (10.78 to 59.70) | −63.5 (−89 to 37.6) |
| Central Europe | 2,871 (1,483 to 4,813) | −87.7 (−95.3 to −61) | 5.24 (2.72 to 8.73) | −79.6 (−92.2 to −35.8) |
| Eastern Europe | 1,345 (957 to 2,056) | −85.4 (−88.4 to −80.2) | 1.50 (1.06 to 2.29) | −73.3 (−79 to −63.3) |
| Australasia | 160 (95 to 253) | −33.3 (−43.3 to −23.5) | 0.86 (0.51 to 1.36) | −43.7 (−52 to −35.3) |
| High-income Asia Pacific | 946 (387 to 2,039) | −98.2 (−99.5 to −87.8) | 1.52 (0.63 to 3.26) | −96.9 (−99.2 to −79.9) |
| High-income North America | 2,342 (1,520 to 3,551) | 40 (8.4 to 75.6) | 1.12 (0.73 to 1.69) | 47.7 (14.5 to 85.7) |
| Southern Latin America | 819 (532 to 1,190) | −81.6 (−87.9 to −72) | 2.08 (1.37 to 3.00) | −76.2 (−84.5 to −63.7) |
| Western Europe | 1,900 (1,230 to 2,914) | −65.9 (−72.9 to −56.7) | 0.89 (0.57 to 1.36) | −62.6 (−70.4 to −51.9) |
| Andean Latin America | 64,967 (20,499 to 140,855) | −67.7 (−91.9 to 28.1) | 114.16 (36.09 to 247.11) | −69.6 (−92.4 to 20.9) |
| Caribbean | 127,542 (23,686 to 306,309) | −35.5 (−85.9 to 211.7) | 326.77 (60.64 to 784.84) | −32 (−85.1 to 228.1) |
| Central Latin America | 18,782 (10,817 to 31,369) | −86.1 (−92.7 to −72.5) | 9.78 (5.66 to 16.27) | −83.5 (−91.3 to −67.3) |
| Tropical Latin America | 10,974 (4,845 to 22,535) | −65.9 (−85.7 to −24) | 7.09 (3.13 to 14.53) | −62.3 (−84.1 to −16.3) |
| North Africa and Middle East | 538,153 (239,090 to 1,060,124) | −69 (−87.9 to −31) | 90.76 (40.18 to 179.79) | −73.2 (−89.6 to −40.2) |
| South Asia | 1,740,745 (509,947 to 3,876,632) | −81.5 (−95.6 to −21) | 109.50 (32.05 to 245.47) | −82.7 (−95.9 to −26.1) |
| East Asia | 93,510 (23,364 to 214,117) | −94.7 (−98.9 to −62.9) | 14.03 (3.58 to 32.00) | −90.9 (−98 to −37.1) |
| Oceania | 65,744 (12,740 to 172,115) | 57.6 (−73.1 to 666.1) | 322.61 (62.44 to 838.74) | −20.4 (−86.4 to 287.1) |
| Southeast Asia | 834,062 (345,358 to 1,623,965) | −70.9 (−89.6 to −25.1) | 152.95 (63.39 to 297.94) | −68.8 (−88.8 to −19.6) |
| Central sub-Saharan Africa | 1,222,476 (364,503 to 2,714,766) | 8.6 (−70.1 to 367.5) | 539.05 (160.46 to 1202.32) | −49.6 (−86.2 to 116.9) |
| Eastern sub-Saharan Africa | 2,079,969 (1,008,770 to 3,913,828) | −41.2 (−74.5 to 35.8) | 312.23 (151.40 to 589.34) | −68.5 (−86.4 to −26.8) |
| Southern sub-Saharan Africa | 125,377 (43,525 to 272,553) | −0.9 (−73.9 to 219.6) | 149.86 (52.00 to 325.72) | −11.8 (−76.8 to 183.6) |
| Western sub-Saharan Africa | 3,168,175 (1,186,950 to 6,998,119) | −5.3 (−63.2 to 163.6) | 382.71 (143.41 to 845.99) | −59.2 (−84.2 to 13.4) |

Values in parentheses represent 95% UIs for numbers, rates and percentage changes. All rates are per 100,000 population.

pandemic-period estimate, rather than a marked worsening beyond the 2019 baseline. Regional patterns varied and are summarized in Supplementary Table 13 and Extended Data Fig. 9b.

In a descriptive post hoc analysis of the high-income super-region, incidence rates in the available broad age groups among people aged 5 years and older were 4.6–5.8% higher in 2023 than in 2019, while the share of cases in children aged 5–9 years changed from 60.30% to 59.77%. These results did not provide evidence of a marked shift in the age structure toward adolescents or adults.

### The association between pertussis burden and SDI

At the national level in 2023, SDI was negatively correlated with age-standardized pertussis burden. Unweighted Pearson correlation coefficients between SDI and ASMR, ASIR and age-standardized DALY rate (ASDR) were −0.732, −0.584 and −0.732, respectively (all $P < 0.001$). Spearman correlations showed similar patterns for ASMR (−0.796), ASIR (−0.578) and ASDR (−0.809). Countries with lower SDI generally had higher modeled mortality and DALY rates, although substantial heterogeneity was observed among countries with similar SDI values (Fig. 4). Because mortality estimates in some high-SDI countries were close to zero, fold-difference comparisons based on extreme country pairs were not emphasized.

## Discussion

This study provides a global assessment of age-specific, sex-specific and location-specific patterns in pertussis burden from 1990 to 2023. The dominant long-term pattern was a decline in age-standardized mortality and incidence, but this progress was uneven. Modeled mortality remained concentrated in sub-Saharan Africa, whereas several high-income settings had persistent or recurrent incidence despite low mortality. The greatest population-adjusted mortality risk occurred among infants before completion of the primary series. Together, these patterns indicate that pertussis control requires different, but complementary, priorities across settings: equitable routine immunization and access to care where mortality is highest, and sustained surveillance and prevention of recurrent transmission where notification systems are strong[1,2,6].

These findings place pertussis within a wider challenge for vaccine-preventable diseases. Progress against diseases such as measles, poliomyelitis, tetanus and pertussis depends on sustained

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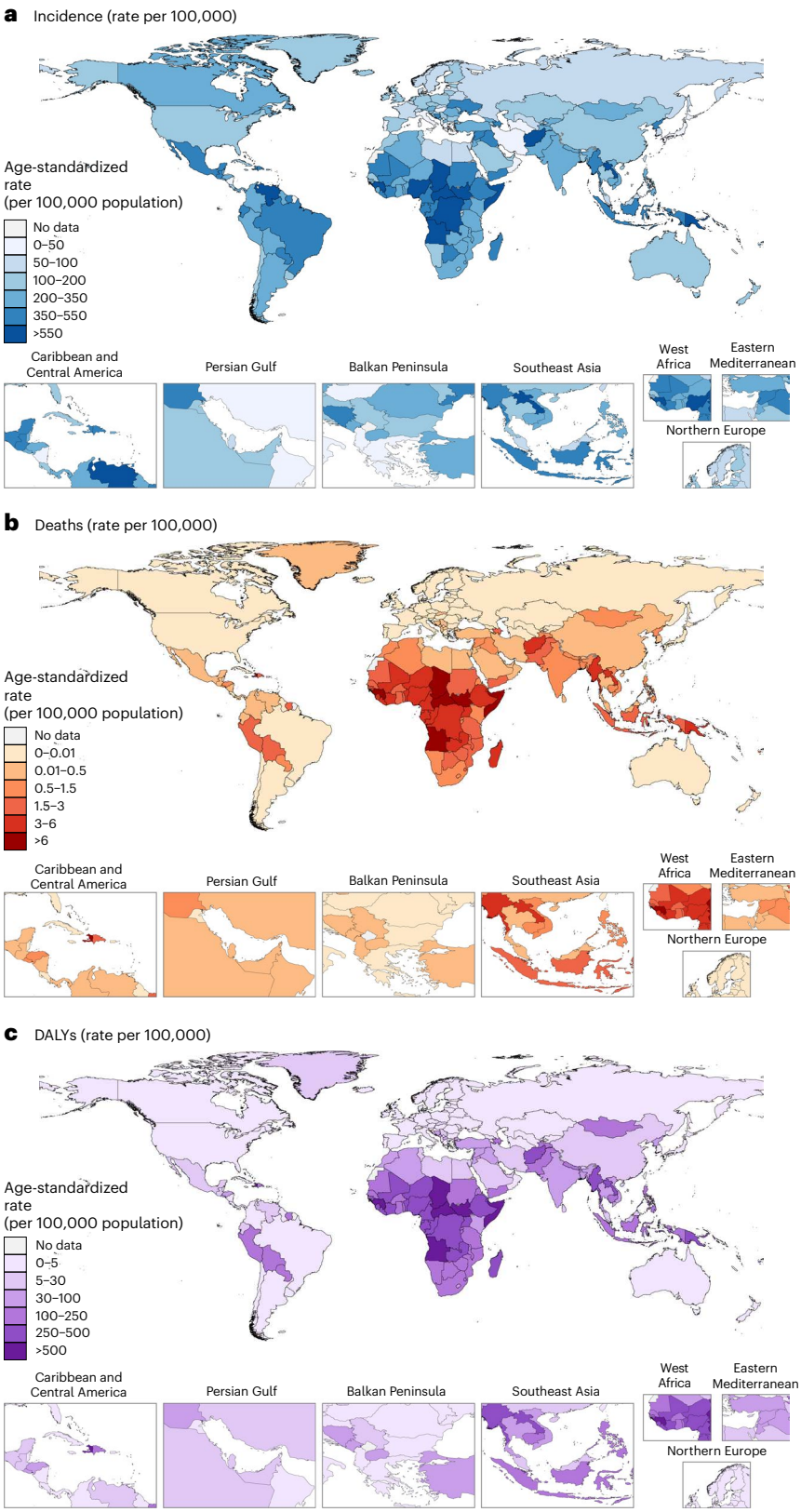



**Fig. 2 | Global distribution of age-standardized pertussis rates and regional hotspots, 2023. a**, ASIR per 100,000 population in 2023. **b**, ASMR per 100,000 population in 2023. **c**, ASDR per 100,000 population in 2023. Colors indicate discrete categories of the GBD 2023 point estimates; gray indicates locations without an estimate. Insets show the Caribbean and Central America, Balkan Peninsula, Northern Europe, Persian Gulf, Southeast Asia, West Africa and Eastern Mediterranean to improve visibility of small geographic areas. Basemap from GADM (https://gadm.org/) under a Creative Commons license CC BY-SA 2.0. All maps were generated by the authors.

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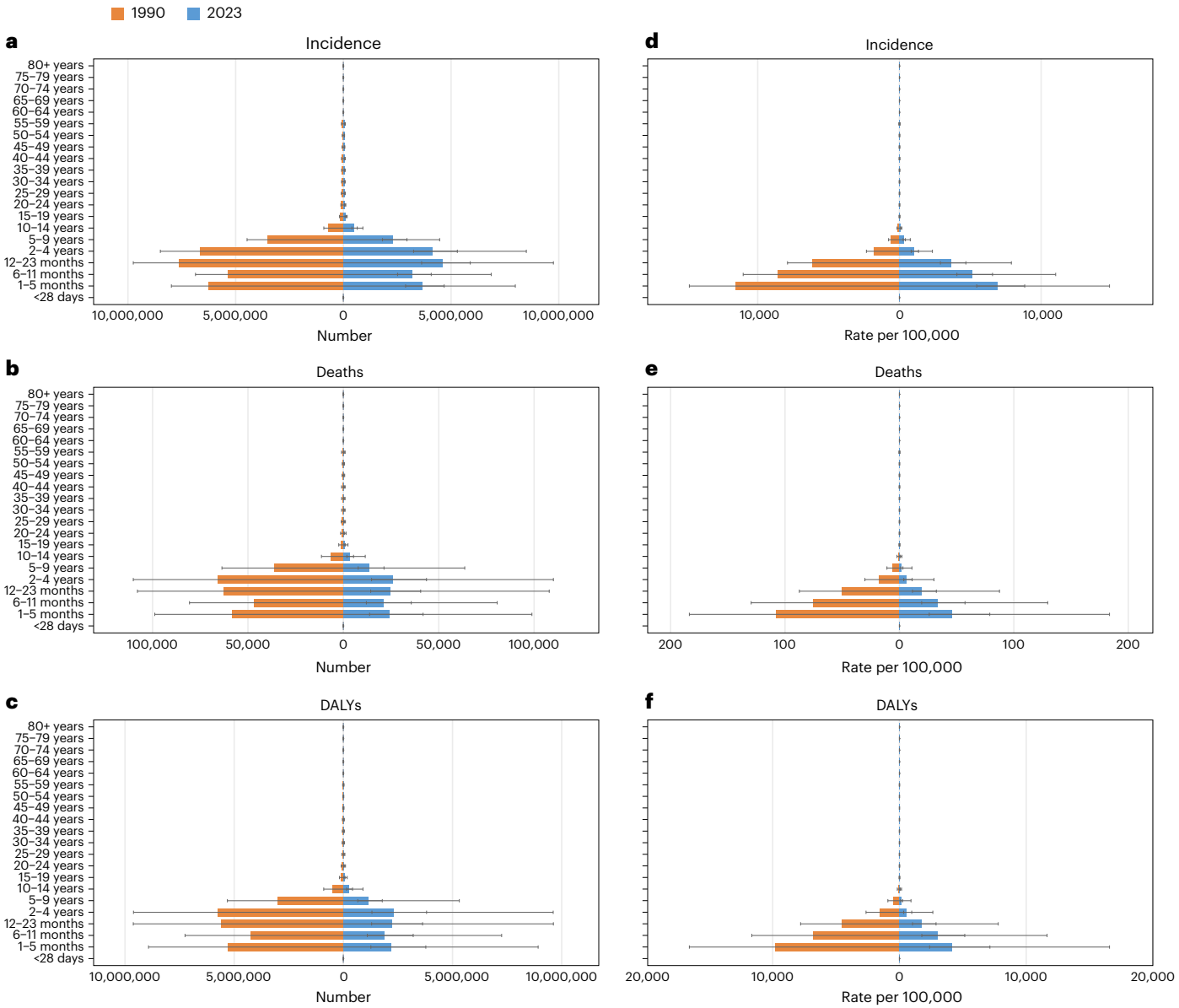



**Fig. 3 | Global pertussis burden by age group in 1990 and 2023. a**, Estimated number of incident cases by age group. **b**, Estimated number of deaths by age group. **c**, Estimated number of DALYs by age group. **d**, Incidence rate per 100,000 population by age group. **e**, Mortality rate per 100,000 population by age group. **f**, DALY rate per 100,000 population by age group. Orange bars show estimates for 1990, and blue bars show estimates for 2023; bar direction is used only to distinguish years and does not indicate negative values. Bars show GBD 2023 point estimates, defined as the means of 1,000 draws; horizontal error bars show 95% UIs, defined by the 2.5th and 97.5th percentiles of the draws. Estimates are for both sexes globally.

delivery of routine vaccination, equitable access to primary care and the capacity to identify and respond to immunity gaps[32,33]. Pertussis should nevertheless not be interpreted through a single template. Its age distribution, waning vaccine-derived protection, diagnostic practices and incomplete case ascertainment differ from those of other vaccine-preventable diseases. Measles can rapidly expose population immunity gaps because of its very high transmissibility, whereas pertussis may remain under-detected in adolescents and adults while causing its most severe outcomes in young infants[9,11,16]. These distinctions support disease-specific surveillance and prevention strategies within integrated immunization programs rather than a uniform response to all vaccine-preventable diseases.

The regional distribution of modeled mortality highlights the importance of strengthening routine immunization in settings with the greatest unmet need. The growing share of global mortality in sub-Saharan Africa reflects slower reductions than in many other regions rather than an observed increase in deaths. This pattern is consistent with the combined effects of gaps in vaccination coverage and timeliness, limited diagnostic and surveillance capacity, barriers to healthcare access, and disruption associated with conflict or fragile health systems[6,34,35]. These factors cannot be disentangled by the present analysis. Nevertheless, practical priorities include dependable vaccine supply, outreach to underserved populations, timely completion of infant doses, and use of subnational coverage and disease data to identify children who are unvaccinated or delayed. Catch-up activities can help restore protection after disruption but should reinforce rather than replace routine primary healthcare.

The infant findings have direct implications for prevention. The global mortality rate among infants aged 1–5 months was similar in 2019 and 2023, and the 2023 rate was at or below the corresponding 2019 level in four of the seven GBD super-regions. This pattern is consistent with resilience of infant immunization services; however,

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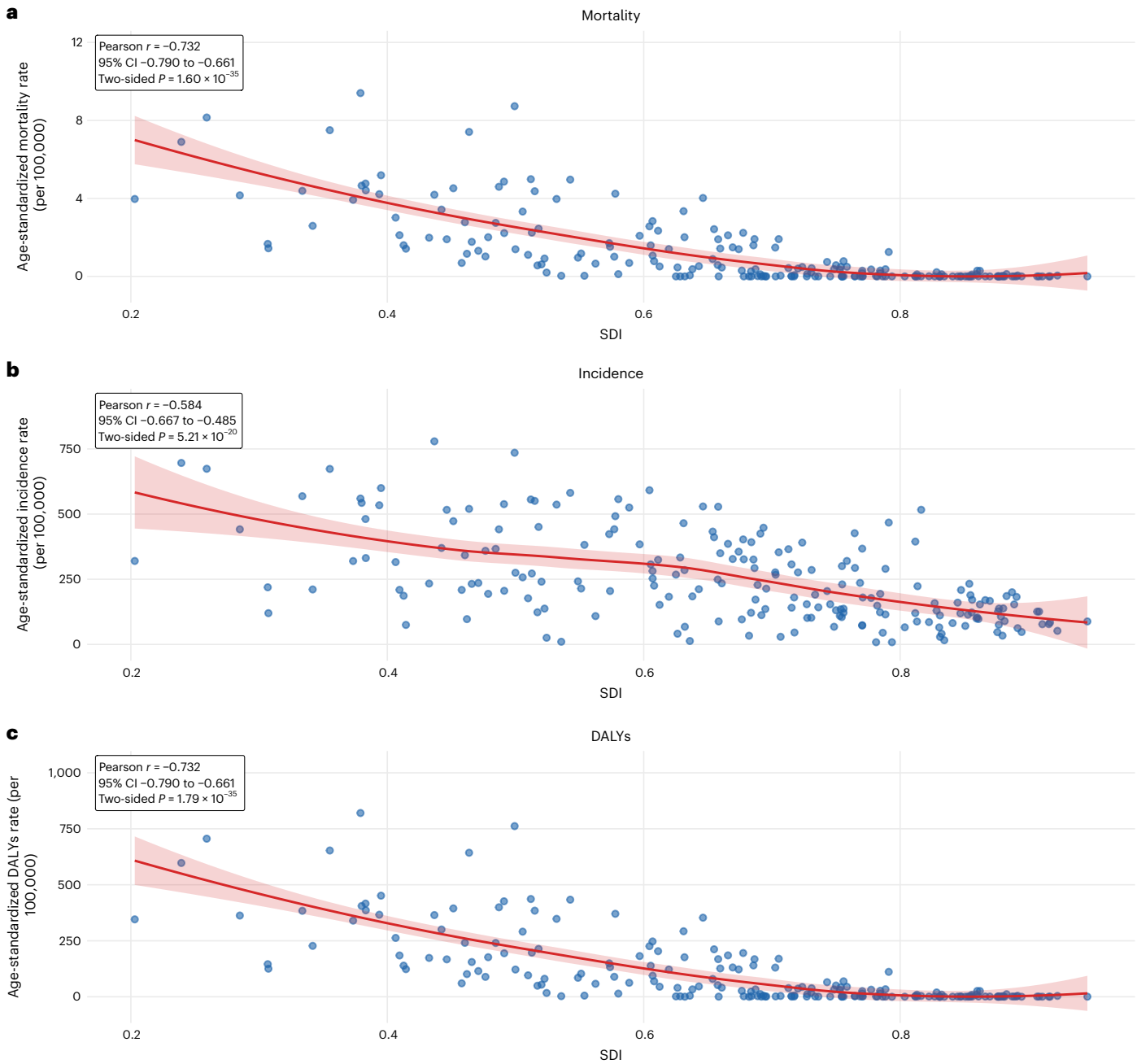



**Fig. 4 | Association between the SDI and age-standardized pertussis burden across countries and territories, 2023. a**, Association between SDI and the ASMR. **b**, Association between SDI and the ASIR. **c**, Association between SDI and ASDR. Each point represents one country or territory ($n = 204$) and shows the GBD 2023 point estimate, defined as the mean of 1,000 draws. Red curves show values fitted using locally estimated scatterplot smoothing (LOESS); shaded areas show pointwise 95% confidence bands around the fitted curves, calculated from the standard errors of the LOESS fits. Associations were assessed using two-sided Pearson product–moment correlation tests and two-sided Spearman rank correlation tests. For mortality, Pearson $r = -0.732$ (95% confidence interval (CI), −0.790 to −0.661; d.f. = 202; $P = 1.60 \times 10^{-35}$) and Spearman $\rho = -0.796$ ($P = 6.90 \times 10^{-46}$). For incidence, Pearson $r = -0.584$ (95% CI, −0.667 to −0.485; d.f. = 202; $P = 5.21 \times 10^{-20}$) and Spearman $\rho = -0.578$ ($P = 1.39 \times 10^{-19}$). For DALYs, Pearson $r = -0.732$ (95% CI, −0.790 to −0.661; d.f. = 202; $P = 1.79 \times 10^{-35}$) and Spearman $\rho = -0.809$ ($P = 1.83 \times 10^{-48}$). No adjustment was made for multiple comparisons because these country-level analyses were descriptive. The LOESS curves and confidence bands are descriptive and were not used for hypothesis testing.

these modeled descriptive trends cannot establish a causal effect of vaccination programs or continuity of immunization services. Severe outcomes remain concentrated in the period before infants complete their primary vaccination series, when protection depends on timely infant doses, maternal antibodies and reduced exposure to infection. Maternal pertussis immunization, where recommended and feasible within national programs, can help bridge this interval and should be considered alongside high-quality antenatal care, prompt recognition of severe infant illness and effective referral pathways[7,26,36–42]. These measures should complement routine childhood vaccination, not compete with it. Although the findings support prioritizing this age group, they do not establish the effectiveness of any individual maternal immunization or infant vaccination program in a particular setting.

In high-income settings, persistent or recurrent incidence after the acute phase of the COVID-19 pandemic warrants continued attention.

In the available broad age groups, the post hoc analysis did not indicate a marked shift in incidence toward adolescents or adults between 2019 and 2023. The absence of harmonized country-level information on vaccine formulation, transition timing and booster schedules precluded attributing the observed pattern to acellular rather than whole-cell vaccines. Observed trends may reflect a combination of changes in contact patterns, healthcare seeking, laboratory testing, reporting, population immunity and circulating strains[9,11,21]. Waning protection after acellular vaccination, changes in booster policies, maternal immunization, pathogen adaptation and antimicrobial resistance are plausible contributors, but the present analysis was not designed to estimate their separate effects. Policies should therefore combine age-appropriate vaccination recommendations with high-quality laboratory confirmation, complete reporting and investigation of severe disease, rather than attribute observed trends to a single vaccine product or mechanism[11,16,43–49].

The post-pandemic context reinforces the value of surveillance, but it also requires careful interpretation. Compared with the unusually low pandemic-period estimates, 2023 burden increased; comparison with the pre-pandemic 2019 baseline, however, suggests a return toward earlier levels rather than evidence of an unprecedented global surge. The GBD 2023 estimates end in 2023 and do not quantify the subsequent reported waves. Public WHO/UNICEF JRF notifications are important for detecting outbreaks and guiding action, but they are not directly equivalent to modeled underlying incidence and should not be used as formal validation targets[50]. More informative surveillance would routinely capture age, vaccination history, laboratory confirmation, hospitalization and outcome, and link these data to local coverage indicators.

This study has several limitations. Estimates are constrained by the availability and quality of incidence and mortality data, particularly in locations with sparse cause-of-death information. The absolute magnitude of the incidence estimates is also sensitive to the choice of Switzerland as the reference for the location-specific random-effect adjustment. This random effect may capture not only incomplete ascertainment but also residual differences in transmission, population structure, vaccination history, diagnostic intensity, reporting requirements and healthcare seeking. The top-five, top-ten and illustrative random-effect value of zero (RE = 0) multipliers are diagnostic sensitivities of this scaling component rather than alternative burden estimates, and this source of structural uncertainty is not fully represented by the draw-based 95% UIs (Supplementary Table 11 and Extended Data Fig. 10). Mortality estimation pathways were geographically patterned: 140 locations used the natural history pathway and 64 used CODEm, including all 46 locations in sub-Saharan Africa, all five locations in South Asia and 20 of 21 locations in North Africa and the Middle East. The final-output mortality-to-incidence ratio was 6.34 deaths per 1,000 estimated cases across natural history locations compared with 0.06 across CODEm locations and was 9.36 in sub-Saharan Africa. These are model-derived ratios rather than observed case-fatality rates (CFRs; Supplementary Table 12 and Extended Data Fig. 9a). Consequently, the modeled concentration of pertussis mortality in data-sparse regions is conditional on the incidence and case-fatality assumptions of the natural history pathway and should not be interpreted as a directly observed geographic distribution of mortality. Differences in diagnostic access, testing practices and notification systems also limit direct comparisons of reported data across countries. The model used simplified, globally comparable inputs and did not directly estimate the effects of vaccine product, booster coverage, maternal immunization, pathogen adaptation or the periodicity of pertussis epidemics. These limitations underline the need for age-specific surveillance, improved information on vaccine timeliness and program delivery, stronger cause-of-death data and evaluation designs capable of assessing causal effects.

In conclusion, the long-term decline in pertussis burden is an important public health achievement, but substantial inequalities remain. Sustained routine immunization, equitable access to primary care, targeted protection of young infants, and surveillance sufficiently sensitive to guide local action are complementary priorities. Coordinating these measures with broader efforts to close immunization gaps for other vaccine-preventable diseases offers a practical route to reducing preventable pertussis morbidity and mortality while strengthening resilient immunization systems.

## Online content

Any methods, additional references, Nature Portfolio reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at https://doi.org/10.1038/s41591-026-04660-8.

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# Methods

## Overview

This study complies with the Guidelines for Accurate and Transparent Health Estimates Reporting (GATHER); the completed checklist is provided in Supplementary Table 1 (ref. 51). This study presents GBD 2023 burden estimates for pertussis incidence, mortality and DALYs across 204 countries and territories, categorized into 21 regions and 7 super-regions. These results supersede all previous GBD estimation rounds. Incorporated newly available data (both internally sourced and via the extensive collaborator network) and refined methods were used to update the complete time series of metrics from 1990 to 2023. To capture age-specific disparities, estimates were generated for detailed age groups including <28 days, 1–5 months, 6–11 months, 12–23 months and 2–4 years, followed by 5-year intervals up to 80+ years. Across all metrics, GBD 2023 drew on the expertise of more than 14,000 collaborators from more than 160 countries and territories. GBD 2023 estimates for pertussis were originally produced by the GBD 2023 Causes of Death Collaborators[52] and GBD 2023 Disease and Injury and Risk Factor Collaborators[53] and shared publicly in the GBD Results Tool (https://vizhub.healthdata.org/gbd-results/); this study analyzes and presents modeled GBD 2023 estimates specific to pertussis. GBD 2023 estimates were available by biological sex, classified as male or female; gender identity was not available in the GBD estimation framework and was therefore not analyzed.

## Case definition

Pertussis (whooping cough) is a subacute respiratory illness caused by infection with the bacterium *B. pertussis*. Early symptoms include fever, rhinitis and conjunctivitis. Progression to lower respiratory tract infection results in classic paroxysmal coughing which can be complicated by pneumonia, apnea and death in severe cases. Cases of pertussis were identified using International Classification of Diseases, 10th Revision (ICD-10) codes A37–A37.91 and Z23.7, and ICD-9 codes 033–033.9, 484.3 and V03.6.

## Pertussis burden estimation process

Detailed general methods for the GBD 2023, including the location hierarchy, disease estimation framework and cause-of-death modeling platform, have been reported previously[52,53]. Here, we briefly describe the pertussis-specific data inputs and modeling procedures.

**Data sources for incidence and mortality.** Pertussis burden in the GBD 2023 was modeled using WHO JRF case notifications as the primary input data source. This was supplemented by historical case notifications and vaccination-coverage surveillance data from the United Kingdom (from 1942 onwards). These historical data were integrated to provide extended paired comparisons of coverage and incidence, thereby strengthening the coefficient estimation for the vaccination-coverage covariate. Mortality inputs were drawn from vital registration, verbal autopsy and surveillance systems across all available locations, alongside literature-based CFRs.

**Incidence estimation and covariates.** To model pertussis incidence across 204 countries and territories, we used a mixed-effects linear regression framework. The outcome variable was the log-transformed incidence rate (cases per 100,000 persons). The model equation was structured as follows in equation (1):

$$Y_{ij} = \beta_0 + \beta_1(\ln_unvacc_{ij}) + \beta_2(\ln_no_mask_{ij}) + u_j + e_{ij} \quad (1)$$

where $Y_{ij}$ represents the log-transformed pertussis incidence rate for year $i$ and location $j$; $\beta_0$ is the fixed-effect intercept; $\beta_1$ and $\beta_2$ are fixed-effect coefficients; $\ln_unvacc_{ij}$ is the log-transformed proxy for the unvaccinated population; $\ln_no_mask_{ij}$ is the log-transformed proxy for lack of mask use; $u_j$ is the location-specific random intercept; and $e_{ij}$ is the residual error term.

To capture population-level vaccine-derived immunity among children under 5 years of age, we utilized the COVID-inclusive DTP3 vaccine coverage. Rather than a static annual measure, we calculated a rolling mean of DTP3 coverage over a 5-year interval to represent cumulative population-level immunity. In the model, this was incorporated as the log-transformed proxy of the unvaccinated population ($\ln_unvacc_{ij}$), explicitly capturing vaccination disruptions caused by the COVID-19 pandemic. To partially account for COVID-19-related mitigation measures, we incorporated a log-transformed proxy for the lack of mask use ($\ln_no_mask_{ij}$). This variable was selected because it had a standardized definition and was available across all 204 GBD locations and years, although it could not capture other pandemic-related changes such as school closures, mobility restrictions, healthcare seeking, diagnostic disruption or reporting delays. Methodologically, both covariates were log-transformed to decrease statistical skewness and optimize predictive performance. In GBD 2023, if the modeled incidence estimates were lower than notified surveillance cases for a specific location-year, the modeled estimate was replaced with the empirical notification count for that location-year to avoid estimating fewer cases than were reported. Prevalence was subsequently calculated assuming an average disease duration of 50 days.

As post hoc descriptive checks, we summarized empirical notification replacement and the sensitivity of the under-ascertainment adjustment to the Switzerland-reference random effect. Empirical notifications replaced modeled incidence estimates in 60 location-years across 15 locations, corresponding to 0.65% of country-years using the 1980–2024 estimation period as a 45-year denominator across 204 countries and territories; using a 25-year sensitivity denominator, the proportion was 1.18%. Replacements were concentrated in the high-income super-region. Switzerland had the highest location-specific random effect in the final incidence model. Using exp(RE_alternative − RE_Switzerland), the mean of the top-five location-specific random effects would multiply the reference random-effect scaling component by 0.39 relative to the Switzerland-reference adjustment, the mean of the top ten by 0.24, and an illustrative no-reference value of RE_alternative = 0 by 0.0069. These calculations describe sensitivity of the scaling component only and are not alternative GBD model runs. Detailed summaries of empirical notification replacement and the reference random-effect sensitivity calculations are provided in Supplementary Table 11 and Extended Data Fig. 10.

**Mortality modeling and uncertainty propagation.** Mortality estimation utilized a dual-track strategy based on data availability. For data-rich locations with complete vital registration, we utilized the Cause of Death Ensemble model (CODEm), integrating spatiotemporal Gaussian process regression (ST-GPR) and covariates including a 5-year lagged COVID-inclusive DTP3 coverage, per-capita COVID-19 infection rates, masking outside the home, and the SDI. For non-data-rich locations, a natural history model was applied ($Deaths_{ij} = Incidence_{ij} \times CFR_{ij}$). Location-year specific CFRs were estimated by fitting a negative binomial model to the literature-derived CFR data, using the Healthcare Access and Quality (HAQ) index as a primary covariate to account for variations in health system performance. The distinction between data-rich and data-sparse settings reflects the availability and quality of cause-of-death input data, which in GBD 2023 is assessed using indicators including death registration completeness and the proportion of deaths assigned to major garbage codes (Supplementary Table 10). To further characterize this dual-track mortality modeling strategy, we summarized the fatal modeling strategy assigned to each country or territory using the final fatal modeling classification available for this analysis. Among the 204 countries and territories included in the analysis, 64 used CODEm and 140 used the natural history model. We then conducted a post hoc descriptive analysis by merging this classification with final GBD 2023 country-level

pertussis deaths and incidence estimates and calculating deaths per 1,000 estimated cases by modeling strategy and GBD super-region. These ratios were used only to describe patterns in the final model outputs and should not be interpreted as observed CFRs or as causal evidence separating true disease severity from surveillance intensity, under-ascertainment or model structure. Additional summaries are provided in Supplementary Table 12 and Extended Data Fig. 9a.

To propagate uncertainty across all modeling stages, we used a comprehensive draw-level approach. First, 1,000 incidence predictions were generated using the estimated variance–covariance matrix from the mixed-effects linear regression. Second, 1,000 samples (draws) were obtained from the posterior distribution to estimate prevalence rates. Finally, the mortality calculation (Deaths = Incidence × CFR) was replicated at the draw level 1,000 times. Final point estimates are reported as the mean of these 1,000 draws, with 95% UIs defined by the 2.5th and 97.5th percentiles. Finally, DALYs were computed by summing years of life lost (YLLs) and years lived with disability (YLDs), assuming each pertussis case represented a moderate episode of acute infectious disease with a disability weight of 0.051 (95% CI 0.032–0.074).

### Statistical analysis

We assessed the burden of pertussis using absolute numbers of cases, deaths and DALYs to capture the magnitude of disease, alongside age-standardized rates to facilitate population-adjusted comparisons across locations. To quantify temporal trends, we calculated the percentage change in both absolute numbers and age-standardized rates for the entire study period (1990–2023) and across specific sub-periods (1990–2000, 2000–2010 and 2010–2023). Additionally, to characterize pandemic-period suppression and early rebound through 2023, we analyzed the overlapping sub-period of 2020–2023. UIs for all estimates were generated using the 2.5th and 97.5th percentiles of the 1,000 draws from the posterior distribution, capturing uncertainty from input data, corrections and model specifications.

To contextualize modeled GBD incidence estimates against reported surveillance data, we compared 2023 country-level GBD modeled incidence estimates with publicly available WHO/UNICEF JRF pertussis reported cases and incidence rates from the WHO Immunization Data Portal (https://immunizationdata.who.int/). We conducted a post hoc descriptive concordance analysis of all-age incidence rates per million and case counts among matched locations, reporting Pearson and Spearman correlations. We also compared the ranks of GBD 2023 modeled cases with WHO/JRF 2024 reported notifications. Zero values were retained for the all-location rank-based analyses; log-scale case-count correlations were limited to locations with positive values across both sources. These WHO/JRF data were used as external surveillance context rather than equivalent modeled GBD estimates of underlying incidence or as formal model validation.

Additionally, we examined the relationship between SDI and age-standardized rates using LOESS to capture nonlinear trends; the fitted curves include 95% confidence bands (shaded areas) to indicate uncertainty. For country-level analyses (2023), each point represents a country. Country-level correlations between SDI and age-standardized rates were calculated using unweighted Pearson correlation coefficients; Spearman correlations were examined as a sensitivity analysis.

Data analyses and visualizations were performed using R software (version 4.4.2; R Foundation for Statistical Computing) and Python (version 3.12.13; Python Software Foundation). For the world maps in Fig. 2, the source of the map shapefiles was Global Administrative Areas—GADM maps and data 2019 (version 3.6; https://gadm.org/), subject to the IHME Free-of-Charge Non-Commercial User Agreement (https://www.healthdata.org/Data-tools-practices/data-practices/ihme-free-charge-non-commercial-user-agreement/). All maps presented in this study were generated by the authors. All tests were two-sided, and a value $P < 0.05$ was considered statistically significant.

### Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

## Data availability

All final GBD 2023 pertussis burden estimates used in this study, including incidence, mortality, years of life lost, years lived with disability and DALYs by location, year, age and sex, are publicly available through the IHME GBD Results Tool (https://vizhub.healthdata.org/gbd-results/) following free user registration. The final population and SDI estimates used to calculate rates and assess country-level associations are also available through the GBD Results Tool. GBD 2023 vaccination-coverage estimates, including DTP3 vaccine coverage, are available through the GHDx vaccination-coverage record (https://ghdx.healthdata.org/record/ihme-data/gbd-2023-vaccination-coverage-1980-2030/). Metadata and citation information for the input datasets used in the GBD 2023 pertussis models are available through the GBD 2023 Sources Tool (https://ghdx.healthdata.org/gbd-2023/sources/). Pertussis incidence inputs included WHO/UNICEF JRF surveillance notifications and historical notification and vaccination-coverage series from the United Kingdom. Mortality inputs included vital-registration, verbal-autopsy and surveillance data, together with literature-derived case-fatality data. Model covariates included vaccination coverage, mask use, COVID-19 infection rates, the SDI and the Healthcare Access and Quality Index. Pertussis-specific audits of nonfatal and fatal input data by country and year, with source metadata, are available at https://explorer.healthdata.org/heatmap?componentType=cause_nf&id=339/ and https://explorer.healthdata.org/heatmap?componentType=cause_cod&id=339/, respectively. WHO/UNICEF JRF pertussis case and incidence data were used both as input data for the GBD pertussis incidence model and for the descriptive external comparison reported in this study. These data are publicly available through the WHO Immunization Data Portal (https://immunizationdata.who.int/global/wiise-detail-page/pertussis-reported-cases-and-incidence/), which provides the country-level reported cases and incidence rates used in the analysis, including the 2023 and 2024 data. All input datasets are cataloged in the GHDx. Publicly available datasets are linked directly from their GHDx records. For datasets available only by application, including some national vital-registration, surveillance and household-survey datasets, the GHDx identifies the data-holding institution and provides access or request procedures where available. Some underlying individual-level or otherwise restricted data are owned by third-party providers and were used by IHME under data-use agreements. These data cannot be redistributed by the authors because of provider ownership, licensing and privacy restrictions. These restrictions do not prevent reproduction of the manuscript-specific secondary analyses using the publicly available final GBD estimates. Supporting data are provided in Supplementary Tables 2–13, including the country-level comparison of GBD estimates and WHO/UNICEF JRF data in Supplementary Table 8. No individual-level data were generated or directly analyzed for the manuscript-specific secondary analyses.

## Code availability

Post-processing and plotting code used to generate the manuscript-specific analyses, main figures and Extended Data figures and tables from the final GBD estimates is archived as version 1.0.0 in Zenodo (https://doi.org/10.5281/zenodo.21547601)[54] and maintained at https://github.com/vingt3/pertussis-gbd-2023/. The archived code is released under the MIT License. The repository contains the analysis and plotting scripts, a README file describing the correspondence between scripts and manuscript display items, the required input filenames and data schemas, software dependencies and instructions for running the analyses. For the statistical code used in the IHME production environment for the underlying GBD estimation, the standard GBD access

conditions apply. The statistical code used for data processing and analysis is available only upon request due to issues of computational size and complexity, in addition to security concerns. To be eligible to receive code access, requests must (1) be from human researchers—not automated entities—who are affiliated with a recognized academic and/or scientific institution, and (2) utilize the code only for one-time use in association with a clearly defined scientific research project that is not for profit. To request access to statistical code, please complete the online GBD Code Access Request Form, which requires a Proposed Research Plan among other relevant information (https://forms.cloud.microsoft/pages/responsepage.aspx?id=W9229i_wGk-SZoBYqxQYL0myuXIUsw8JKjgsABGwsZYxURVM1OElQUUFSNVk4TzF-CUkozTFhTUVVXSC4u&route=shorturl/). Additionally, please send an email to gbdsec@uw.edu, using the subject line 'GBD Code Access Request', with notification of your request and confirmation that the GBD Code Access Request Form has been completed and submitted. Once the email and the fully completed form have been received, access to code will be provided within 4 weeks of the request date for proposals deemed fully compliant.

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## Additional information

**Extended data** is available for this paper at https://doi.org/10.1038/s41591-026-04660-8.

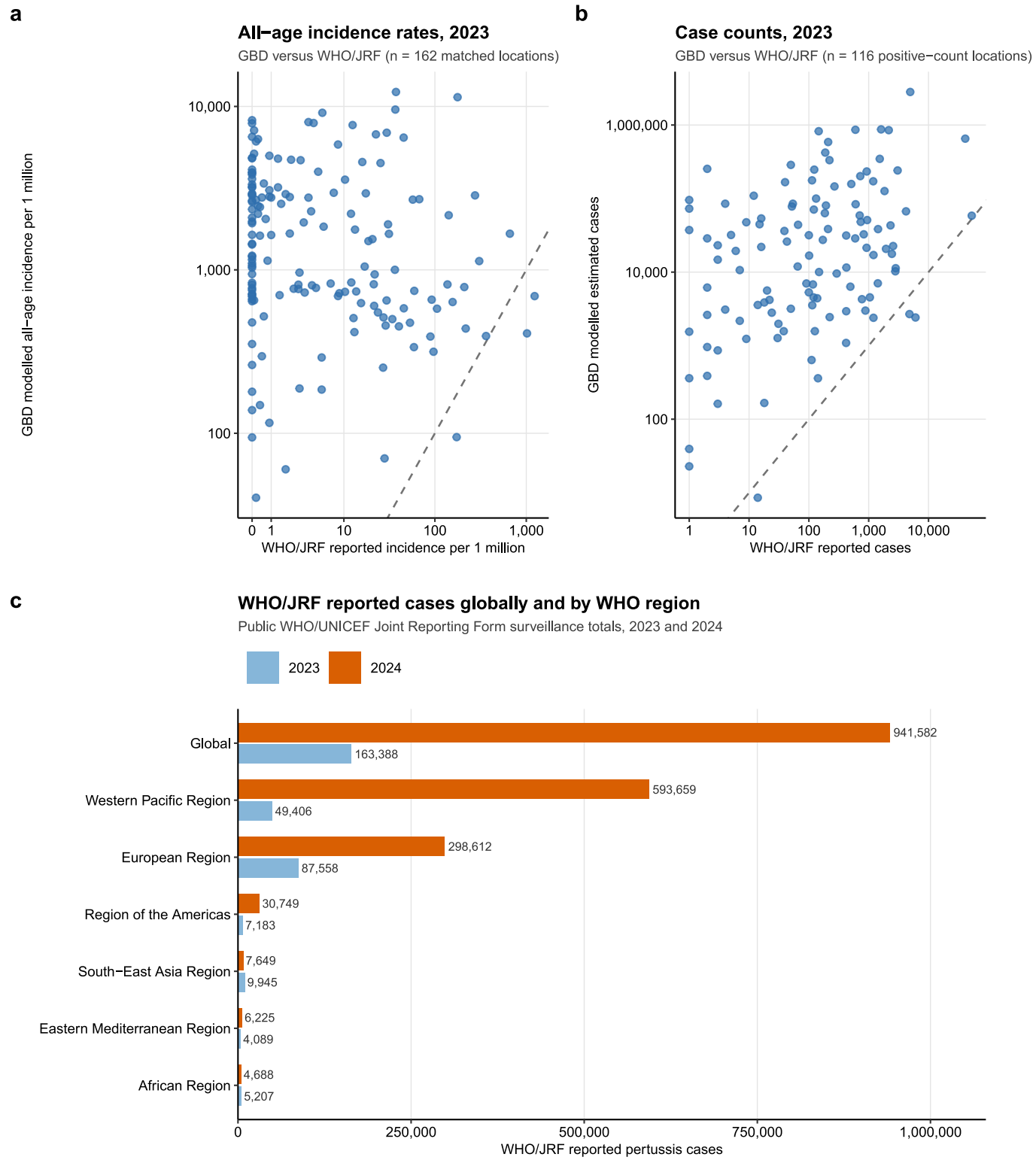
**Supplementary information** The online version contains supplementary material available at https://doi.org/10.1038/s41591-026-04660-8.

**Correspondence and requests for materials** should be addressed to Jonathan F. Mosser or Jue Liu.

**Peer review information** *Nature Medicine* thanks Matthieu Domenech de Cellès, Hirotake Mori and the other, anonymous, reviewer(s) for their contribution to the peer review of this work. Peer reviewer reports are available. Primary Handling Editor: Ming Yang, in collaboration with the *Nature Medicine* team.

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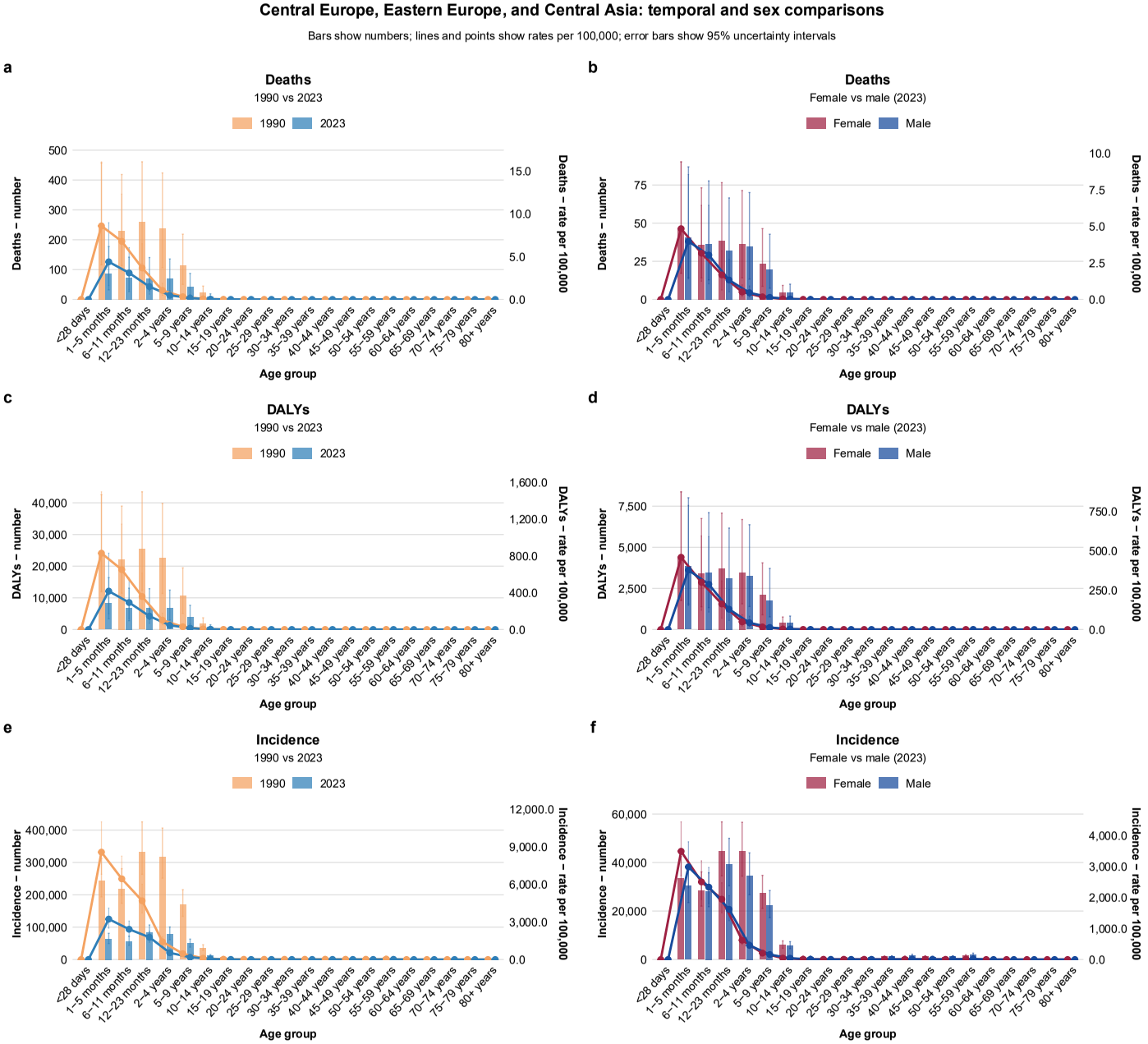



**Extended Data Fig. 1 | See next page for caption.**

https://doi.org/10.1038/s41591-026-04660-8

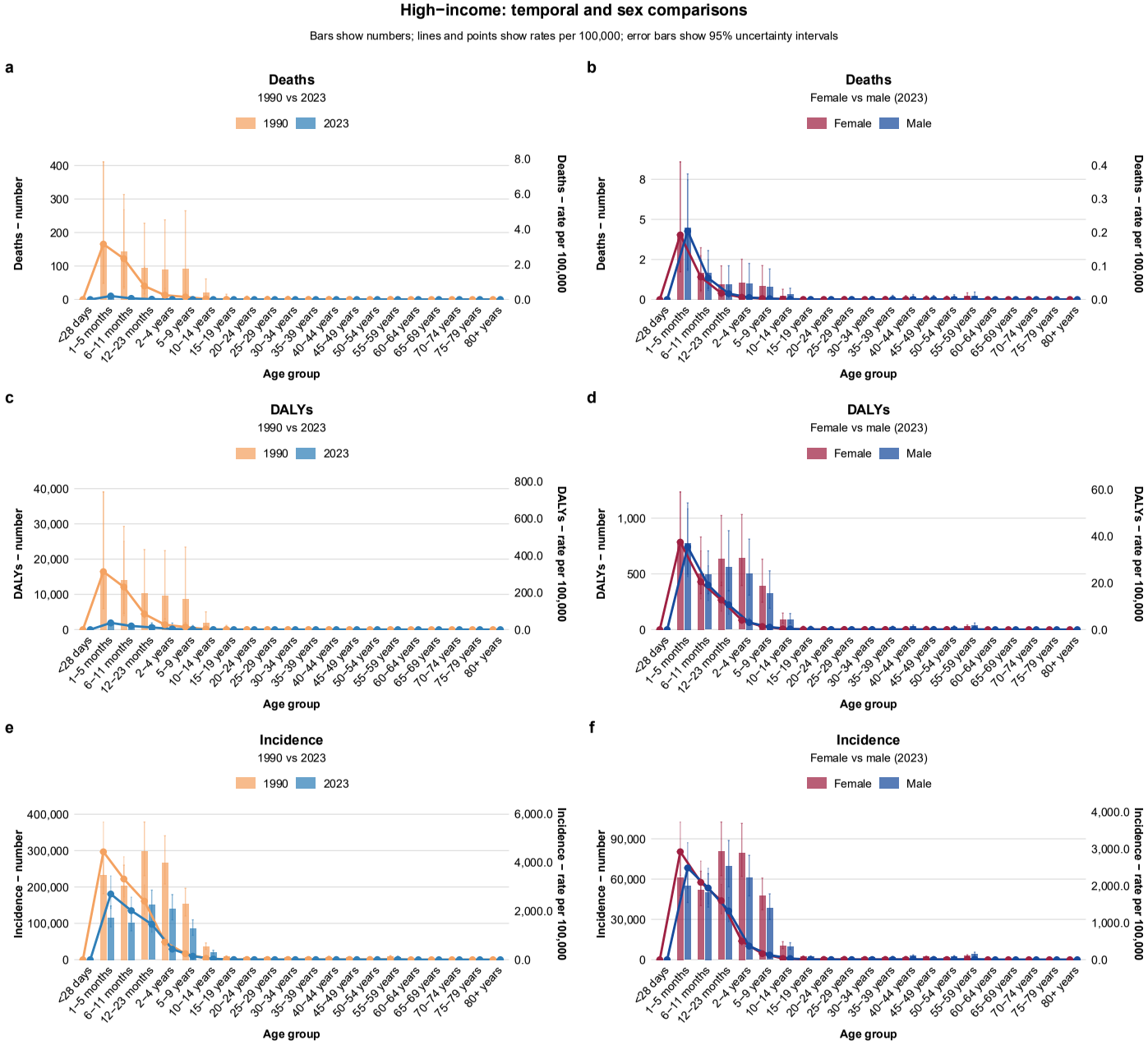
**Extended Data Fig. 1 | External comparison of GBD 2023 modelled pertussis incidence estimates with WHO/UNICEF Joint Reporting Form surveillance data. a**, Country-level comparison of GBD 2023 modelled all-age pertussis incidence rates and WHO/UNICEF Joint Reporting Form (JRF) reported incidence rates in 2023 (n = 162 matched locations). GBD point estimates are means of 1,000 draws. Both axes use the same base-10 pseudo-log transformation (sigma = 1), retaining zero-valued WHO/JRF reports; the dashed line indicates equality. The two-sided Pearson correlation was r = −0.103 (95% confidence interval (CI), −0.253 to 0.052; degrees of freedom (df) = 160; P = 0.190899), and the two-sided Spearman correlation was ρ = −0.180 (P = 0.022036). **b**, Country-level comparison of GBD 2023 modelled and WHO/JRF reported pertussis case counts in 2023 among locations with positive counts in both sources (n = 116 locations). Both axes use base-10 logarithmic scales; the dashed line indicates equality. The two-sided Pearson correlation was r = 0.398 (95% CI, 0.233 to 0.541; df = 114; P = 9.47191 × 10^ − 6), and the two-sided Spearman correlation was ρ = 0.348 (P = 0.000131791). **c**, WHO/JRF reported pertussis case counts globally and by WHO region in 2023 (blue) and 2024 (orange). Values are surveillance totals; no error bars are shown. The 2024 data occurred after the GBD 2023 estimation period and are presented as descriptive surveillance context. No adjustment was made for multiple comparisons because the analyses were descriptive. WHO/JRF notifications and GBD modelled underlying incidence are distinct estimands; these comparisons are not formal validation. GBD, Global Burden of Disease Study; UNICEF, United Nations Children's Fund; WHO, World Health Organization.

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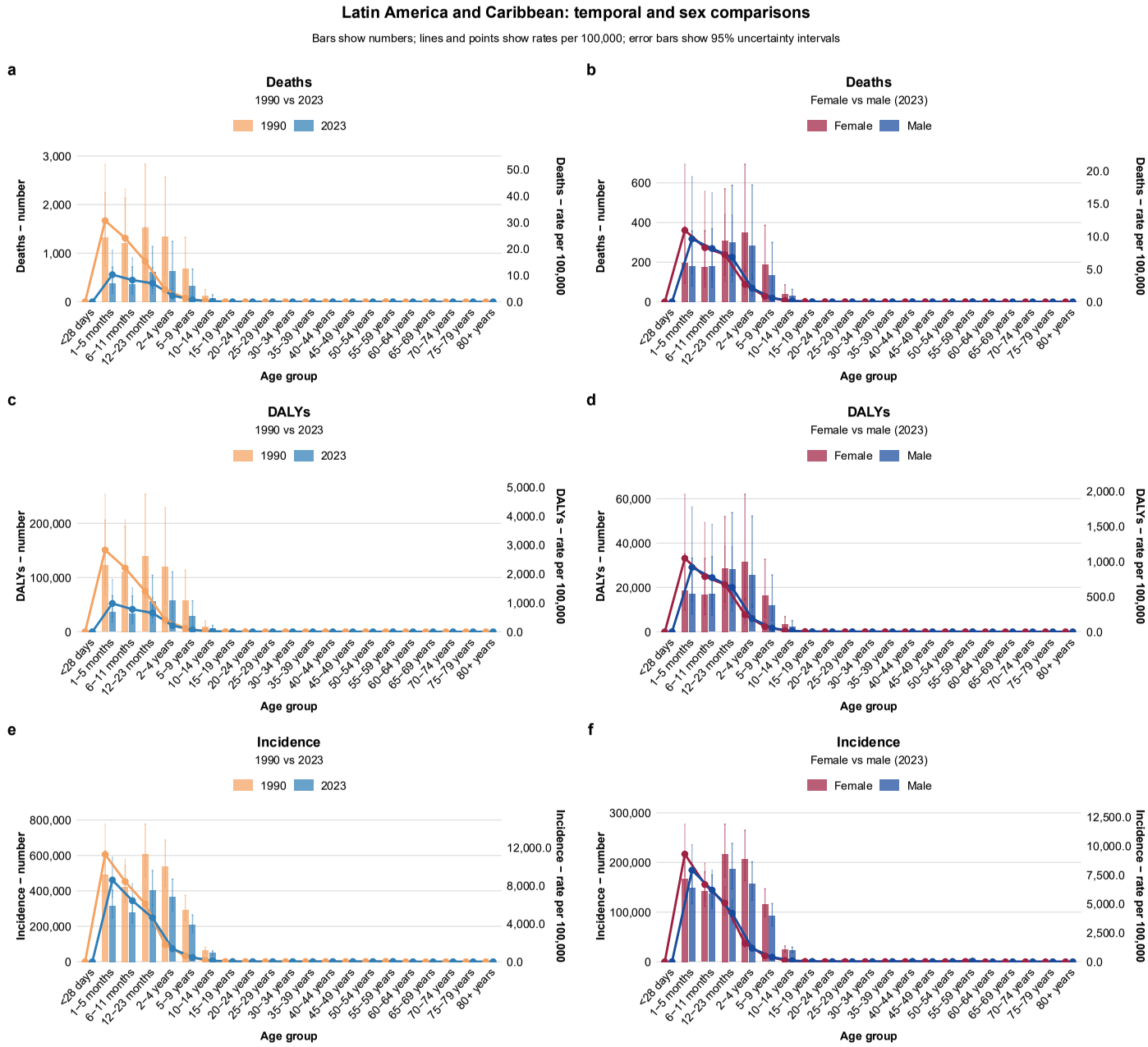

**Extended Data Fig. 2 | Age distribution of pertussis deaths, incidence, and DALYs in Central Europe, Eastern Europe, and Central Asia: temporal and sex comparisons. a**, **c** and **e**, Age-specific numbers and rates for deaths, DALYs and incidence, respectively, comparing 1990 with 2023. **b**, **d** and **f**, Corresponding age-specific numbers and rates comparing females and males in 2023. Bars show GBD 2023 point estimates for absolute numbers, and lines show point estimates for rates per 100,000 population. Point estimates are defined as the means of 1,000 draws; error bars show 95% uncertainty intervals, defined by the 2.5th and 97.5th percentiles of the draws.

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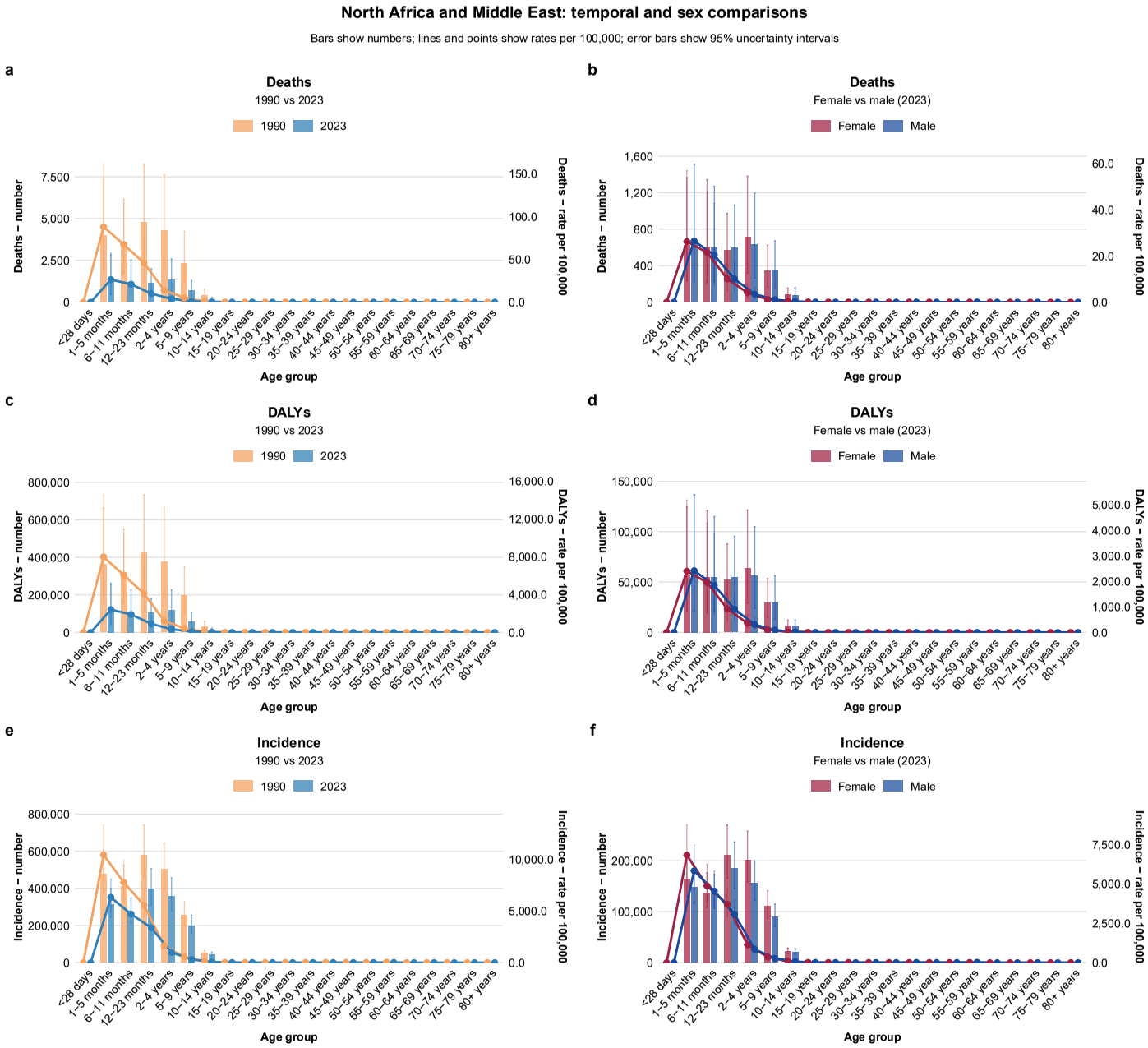

**Extended Data Fig. 3 | Age distribution of pertussis deaths, incidence, and DALYs in High-income Region: temporal and sex comparisons. a**, **c** and **e**, Age-specific numbers and rates for deaths, DALYs and incidence, respectively, comparing 1990 with 2023. **b**, **d** and **f**, Corresponding age-specific numbers and rates comparing females and males in 2023. Bars show GBD 2023 point estimates for absolute numbers, and lines show point estimates for rates per 100,000 population. Point estimates are defined as the means of 1,000 draws; error bars show 95% uncertainty intervals, defined by the 2.5th and 97.5th percentiles of the draws.

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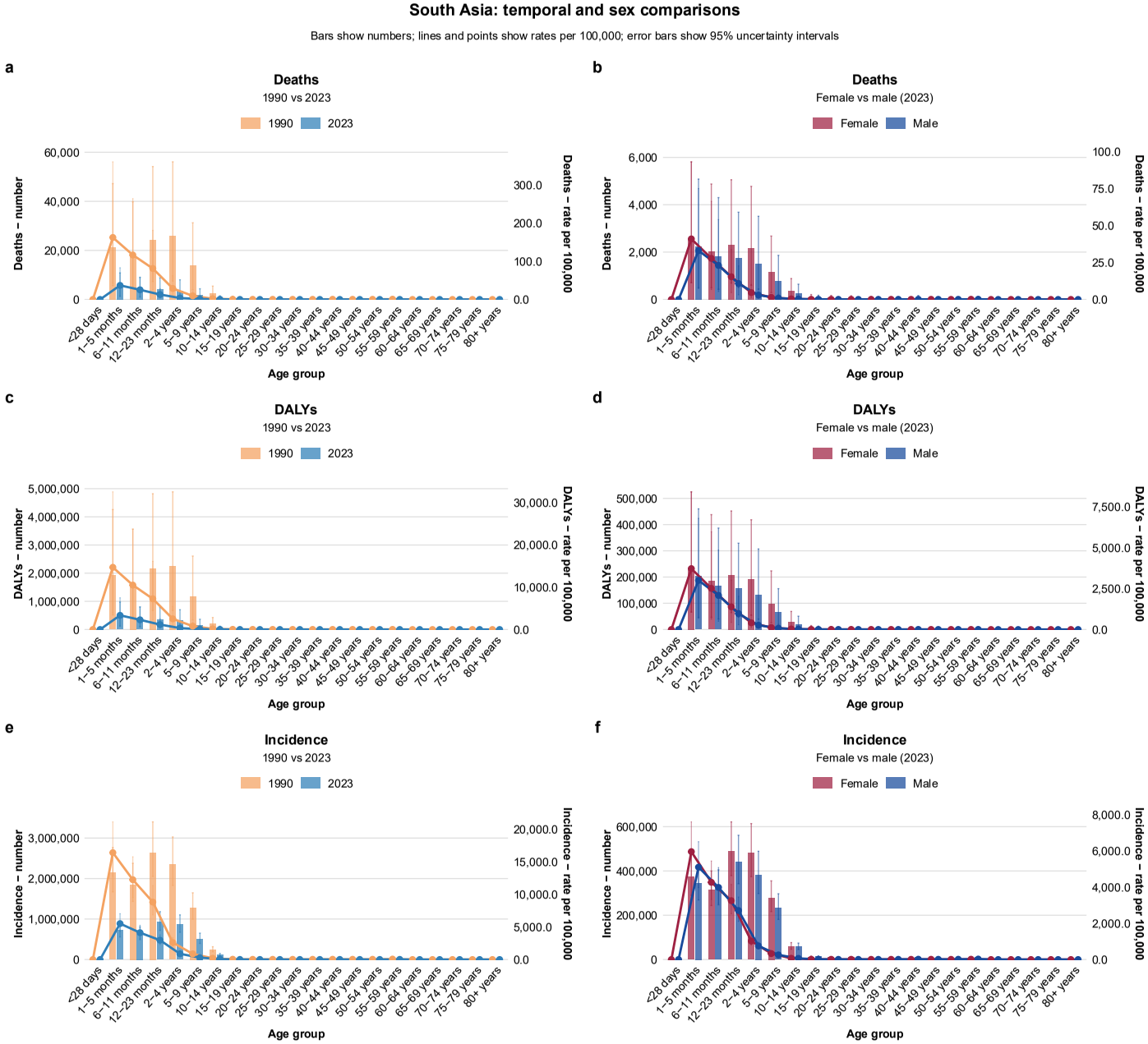

**Extended Data Fig. 4 | Age distribution of pertussis deaths, incidence, and DALYs in Latin America and Caribbean: temporal and sex comparisons.** **a**, **c** and **e**, Age-specific numbers and rates for deaths, DALYs and incidence, respectively, comparing 1990 with 2023. **b**, **d** and **f**, Corresponding age-specific numbers and rates comparing females and males in 2023. Bars show GBD 2023 point estimates for absolute numbers, and lines show point estimates for rates per 100,000 population. Point estimates are defined as the means of 1,000 draws; error bars show 95% uncertainty intervals, defined by the 2.5th and 97.5th percentiles of the draws.

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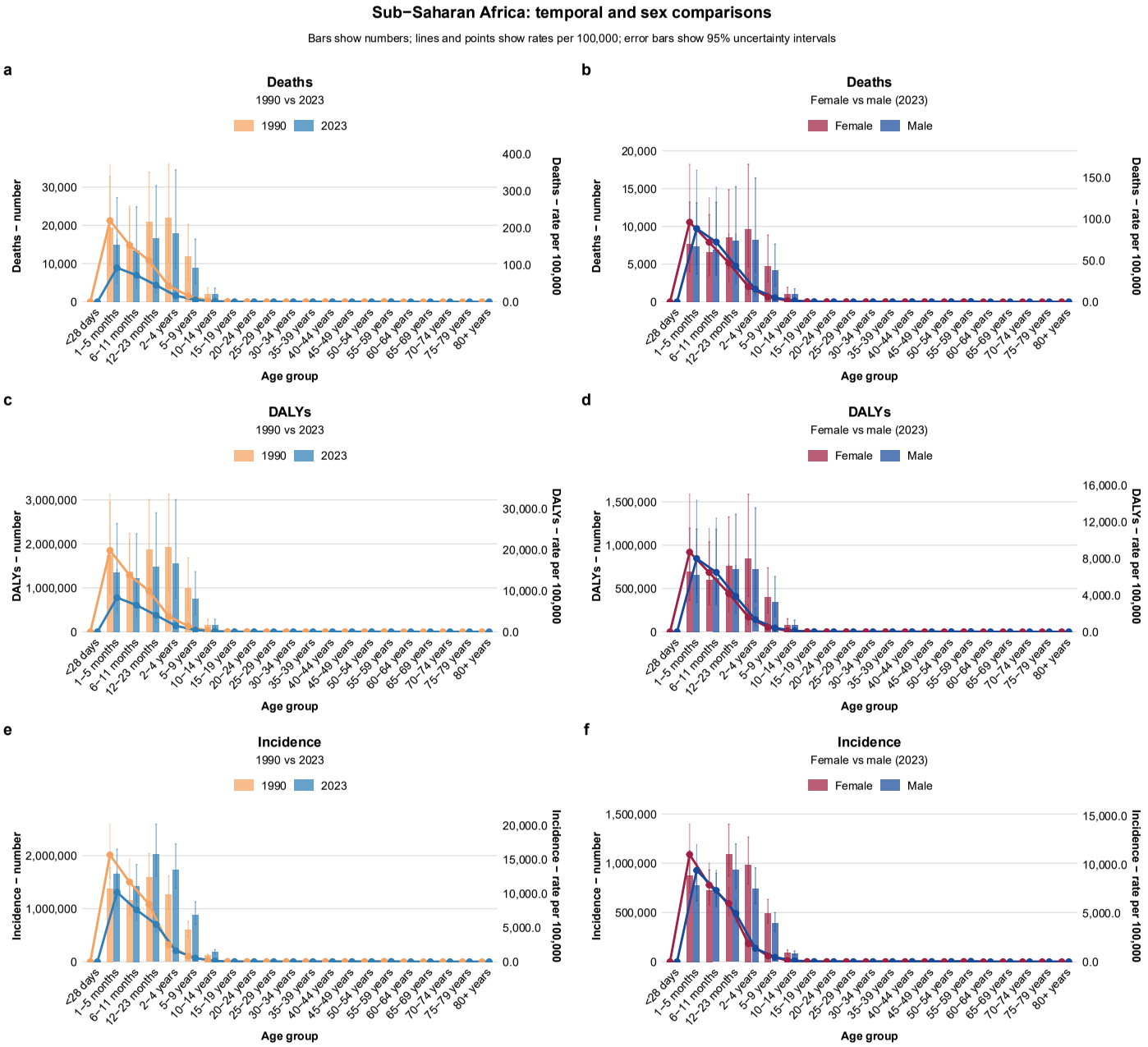

**Extended Data Fig. 5 | Age distribution of pertussis deaths, incidence, and DALYs in North Africa and Middle East: temporal and sex comparisons.** **a**, **c** and **e**, Age-specific numbers and rates for deaths, DALYs and incidence, respectively, comparing 1990 with 2023. **b**, **d** and **f**, Corresponding age-specific numbers and rates comparing females and males in 2023. Bars show GBD 2023 point estimates for absolute numbers, and lines show point estimates for rates per 100,000 population. Point estimates are defined as the means of 1,000 draws; error bars show 95% uncertainty intervals, defined by the 2.5th and 97.5th percentiles of the draws.

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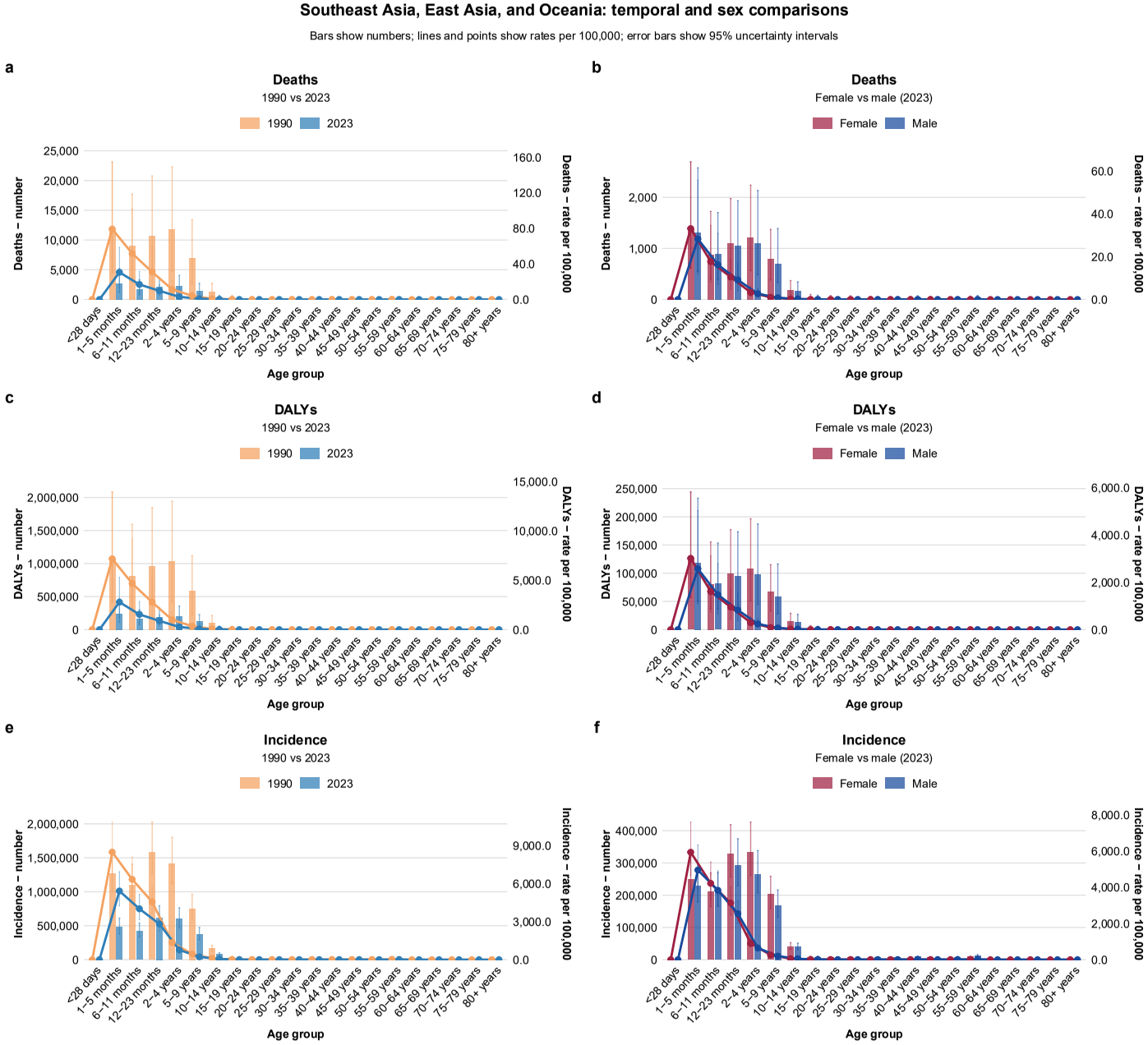

**Extended Data Fig. 6 | Age distribution of pertussis deaths, incidence, and DALYs in South Asia: temporal and sex comparisons. a**, **c** and **e**, Age-specific numbers and rates for deaths, DALYs and incidence, respectively, comparing 1990 with 2023. **b**, **d** and **f**, Corresponding age-specific numbers and rates comparing females and males in 2023. Bars show GBD 2023 point estimates for absolute numbers, and lines show point estimates for rates per 100,000 population. Point estimates are defined as the means of 1,000 draws; error bars show 95% uncertainty intervals, defined by the 2.5th and 97.5th percentiles of the draws.

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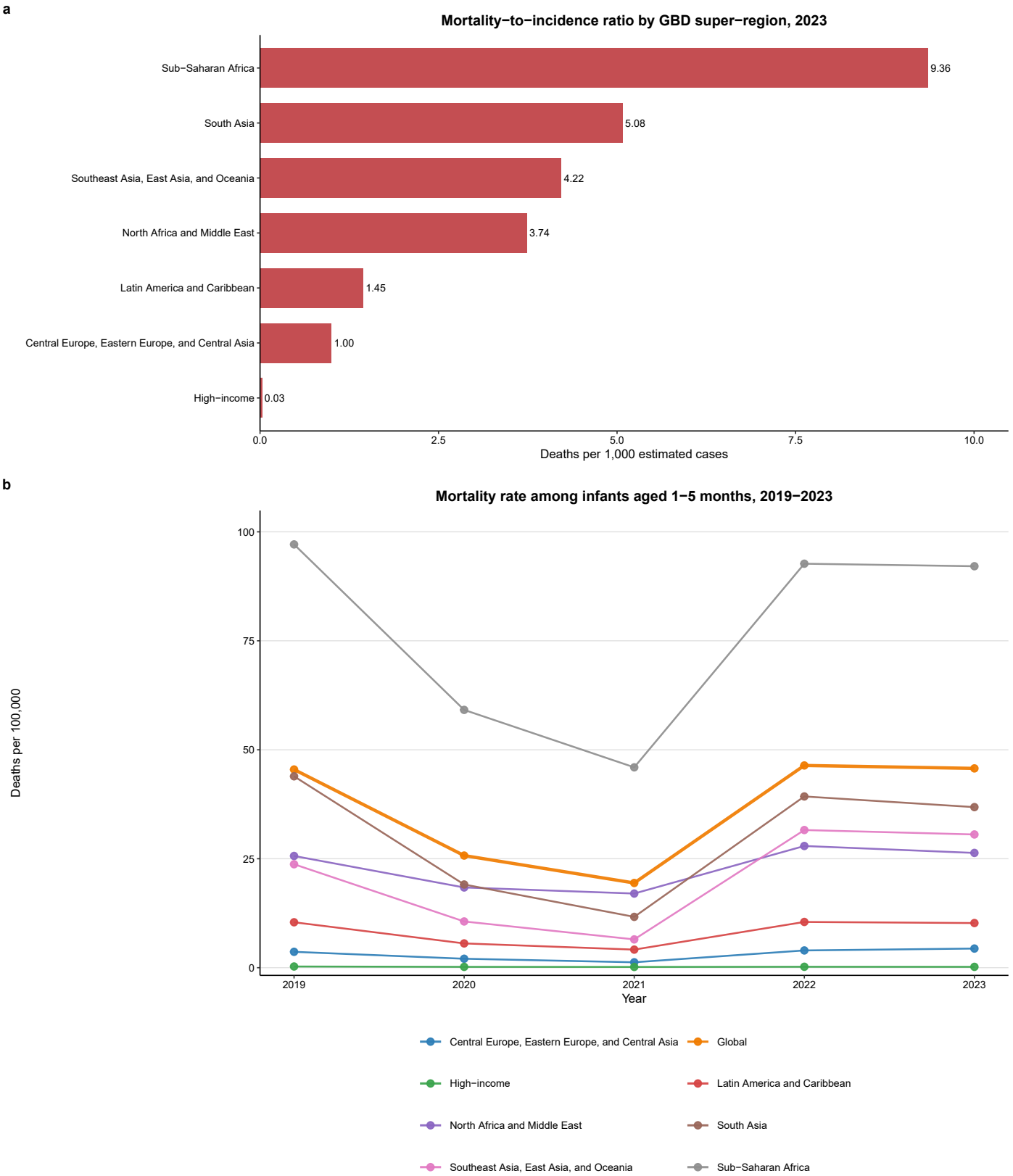

**Extended Data Fig. 7 | Age distribution of pertussis deaths, incidence, and DALYs in Sub-Saharan Africa: temporal and sex comparisons. a**, **c** and **e**, Age-specific numbers and rates for deaths, DALYs and incidence, respectively, comparing 1990 with 2023. **b**, **d** and **f**, Corresponding age-specific numbers and rates comparing females and males in 2023. Bars show GBD 2023 point estimates for absolute numbers, and lines show point estimates for rates per 100,000 population. Point estimates are defined as the means of 1,000 draws; error bars show 95% uncertainty intervals, defined by the 2.5th and 97.5th percentiles of the draws.

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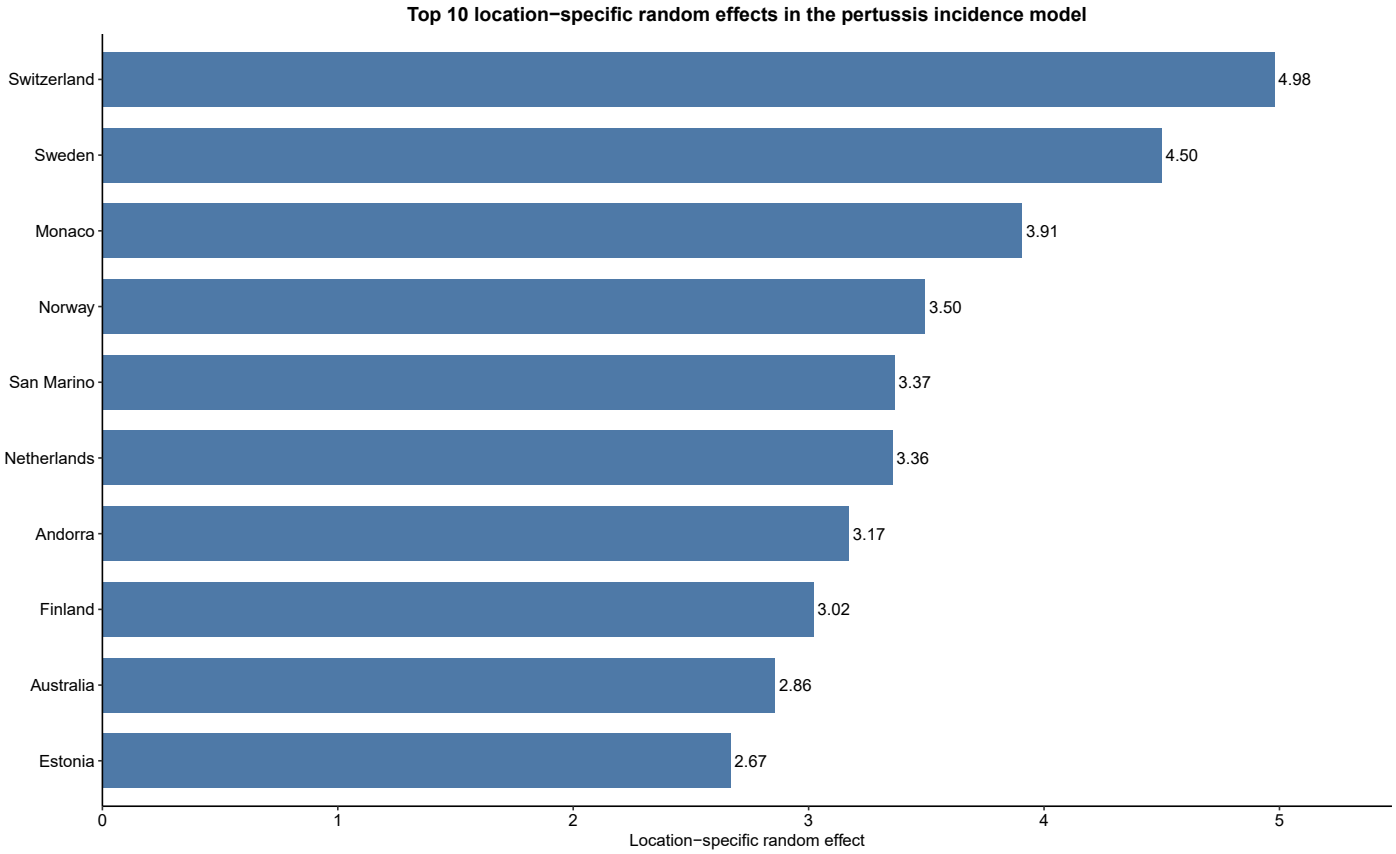

**Extended Data Fig. 8 | Age distribution of pertussis deaths, incidence, and DALYs in Southeast Asia, East Asia, and Oceania: temporal and sex comparisons.** **a**, **c** and **e**, Age-specific numbers and rates for deaths, DALYs and incidence, respectively, comparing 1990 with 2023. **b**, **d** and **f**, Corresponding age-specific numbers and rates comparing females and males in 2023. Bars show GBD 2023 point estimates for absolute numbers, and lines show point estimates for rates per 100,000 population. Point estimates are defined as the means of 1,000 draws; error bars show 95% uncertainty intervals, defined by the 2.5th and 97.5th percentiles of the draws.

https://doi.org/10.1038/s41591-026-04660-8




**Extended Data Fig. 9 | Mortality-to-incidence ratios by GBD super-region and mortality rates among infants aged 1–5 months. a**, Estimated pertussis deaths per 1,000 estimated cases in 2023, by GBD super-region. This is a model-derived mortality-to-incidence ratio, not an observed case-fatality ratio. Death estimates in the final model were generated through CODEm in data-rich settings and through a natural-history pathway, combining modelled incidence with case-fatality ratios, in data-sparse settings. Therefore, the mortality-to-incidence ratio reflects the final model output and the mix of mortality estimation pathways; it is not an observed case-fatality ratio. **b**, Estimated pertussis mortality rates per 100,000 population among infants aged 1–5 months, by GBD super-region and globally, from 2019 to 2023. Estimates are model outputs and should be interpreted with the uncertainty and data-availability limitations of the underlying mortality estimation pathways.

https://doi.org/10.1038/s41591-026-04660-8




**Extended Data Fig. 10 | Top 10 location-specific random effects in the pertussis incidence model.** Switzerland had the highest random effect and was used as the reference location for the under-ascertainment adjustment. Multipliers are relative to the Switzerland-reference adjustment and describe only the reference random-effect scaling component, holding all other model components fixed. Using the mean of the top five random effects instead of Switzerland alone would multiply this scaling component by 0.39; using the mean of the top ten random effects would multiply it by 0.24. The no-reference RE = 0 scenario would multiply the scaling component by 0.0069, but is shown only as an extreme diagnostic lower-bound illustration, not as a plausible alternative model. These calculations are not alternative GBD estimates and should not be interpreted as revised incidence, mortality, or DALY estimates.

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Corresponding author(s): Jonathan F Mosser, Jue Liu

Last updated by author(s): Aug 19, 2026

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## Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

| n/a | Confirmed |
|---|---|
| ☐ | ☒ The exact sample size (*n*) for each experimental group/condition, given as a discrete number and unit of measurement |
| ☐ | ☒ A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly |
| ☐ | ☒ The statistical test(s) used AND whether they are one- or two-sided<br>*Only common tests should be described solely by name; describe more complex techniques in the Methods section.* |
| ☐ | ☒ A description of all covariates tested |
| ☐ | ☒ A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons |
| ☐ | ☒ A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals) |
| ☐ | ☒ For null hypothesis testing, the test statistic (e.g. *F*, *t*, *r*) with confidence intervals, effect sizes, degrees of freedom and *P* value noted<br>*Give P values as exact values whenever suitable.* |
| ☒ | ☐ For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings |
| ☒ | ☐ For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes |
| ☐ | ☒ Estimates of effect sizes (e.g. Cohen's *d*, Pearson's *r*), indicating how they were calculated |

*Our web collection on statistics for biologists contains articles on many of the points above.*

## Software and code

Policy information about availability of computer code

| | |
|---|---|
| Data collection | No software was used for data collection for this analysis. |
| Data analysis | Post-processing and plotting code used to generate the manuscript-specific analyses, figures and tables from final GBD estimates is publicly available in Zenodo (version 1.0.0; https://doi.org/10.5281/zenodo.21547601) and GitHub (https://github.com/vingt3/pertussis-gbd-2023) under the MIT License. Statistical code used in the IHME production environment for the underlying GBD estimation is available through the standard GBD Code Access Request process (https://forms.cloud.microsoft/pages/responsepage.aspx?id=W9229i_wGkSZoBYqxQYL0myuXIUsw8JKjgsABGwsZYxURVM1OElQUUFSNVk4TzFCUkozTFhTUVVXSC4u&route=shorturl) because of computational size and complexity and security concerns. Eligible researchers should complete the GBD Code Access Request Form and notify gbdsec@uw.edu using the subject line "GBD Code Access Request". Access will be provided within four weeks for fully compliant proposals. |

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## Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our policy

All final GBD 2023 pertussis burden estimates used in this study, including incidence, mortality, years of life lost, years lived with disability and disability-adjusted life years by location, year, age and sex, are publicly available through the IHME GBD Results Tool (https://vizhub.healthdata.org/gbd-results) following free user registration. The final population and Socio-demographic Index estimates used to calculate rates and assess country-level associations are also available through the GBD Results Tool. GBD 2023 vaccination coverage estimates, including third-dose diphtheria–tetanus–pertussis vaccine coverage, are available through the GHDx vaccination coverage record (https://ghdx.healthdata.org/record/ihme-data/gbd-2023-vaccination-coverage-1980-2030).
Metadata and citation information for the input datasets used in the GBD 2023 pertussis models are available through the GBD 2023 Sources Tool (https://ghdx.healthdata.org/gbd-2023/sources). Pertussis incidence inputs included WHO/UNICEF Joint Reporting Form surveillance notifications and historical notification and vaccination-coverage series from the United Kingdom. Mortality inputs included vital-registration, verbal-autopsy and surveillance data, together with literature-derived case-fatality data. Model covariates included vaccination coverage, mask use, COVID-19 infection rates, the Socio-demographic Index and the Healthcare Access and Quality Index. Pertussis-specific audits of non-fatal and fatal input data by country and year, with source metadata, are available at https://explorer.healthdata.org/heatmap?componentType=cause_nf&id=339 and https://explorer.healthdata.org/heatmap?componentType=cause_cod&id=339, respectively.
WHO/UNICEF Joint Reporting Form (JRF) pertussis case and incidence data were used both as input data for the GBD pertussis incidence model and for the descriptive external comparison reported in this study. These data are publicly available through the WHO Immunization Data Portal (https://immunizationdata.who.int/global/wiise-detail-page/pertussis-reported-cases-and-incidence), which provides the country-level reported cases and incidence rates used in the analysis, including the 2023 and 2024 data.
All input datasets are catalogued in the GHDx. Publicly available datasets are linked directly from their GHDx records. For datasets available only by application, including some national vital-registration, surveillance and household-survey datasets, the GHDx identifies the data-holding institution and provides access or request procedures where available. Some underlying individual-level or otherwise restricted data are owned by third-party providers and were used by IHME under data-use agreements. These data cannot be redistributed by the authors because of provider ownership, licensing and privacy restrictions. These restrictions do not prevent reproduction of the manuscript-specific secondary analyses using the publicly available final GBD estimates.
Supporting data published alongside this article are provided in Supplementary Tables S2–S13, including the country-level comparison of GBD estimates and WHO/UNICEF JRF data in Supplementary Table S8. No individual-level data were generated or directly analysed for the manuscript-specific secondary analyses.

## Research involving human participants, their data, or biological material

Policy information about studies with human participants or human data. See also policy information about sex, gender (identity/presentation), and sexual orientation and race, ethnicity and racism.

| | |
|---|---|
| Reporting on sex and gender | This study used sex-stratified estimates from the Global Burden of Diseases, Injuries, and Risk Factors Study 2023. Results were estimated and reported for males, females, and both sexes combined, according to the sex categories used in the GBD 2023 estimation framework and population data. Sex was incorporated in the estimation and reporting of incidence, mortality, DALYs, and age-standardized rates where available. This study did not involve primary data collection and did not collect or analyse information on gender identity, gender expression, or sexual orientation. Therefore, analyses by gender identity were not performed. |
| Reporting on race, ethnicity, or other socially relevant groupings | Race, ethnicity and other socially relevant groupings were not available in the GBD 2023 estimation framework and were therefore not analysed. |
| Population characteristics | The analysis included aggregated GBD 2023 estimates for all ages and both sexes across 204 countries and territories from 1990 to 2023. No individual-level participant data were analysed. |
| Recruitment | No participants were recruited because this study was a secondary analysis of aggregated population-level estimates. |
| Ethics oversight | The GBD study protocol was approved by the University of Washington Institutional Review Board. This study used secondary, aggregated, de-identified GBD 2023 estimates and involved no primary data collection. |

Note that full information on the approval of the study protocol must also be provided in the manuscript.

# Field-specific reporting

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# Life sciences study design

All studies must disclose on these points even when the disclosure is negative.

| | |
|---|---|
| Sample size | The sample size used in the study model is defined as the population from all locations analyzed from 1990 to 2023. We included all available location-level estimates from the Global Burden of Disease Study 2023, covering 204 countries and territories, categorized into 21 regions and seven broad super-regions. The population at the national, regional, super-regional, and global levels was estimated as part of GBD 2023 and represents the global population based on demographic characteristics such as age (<28 days, 1–5 months, 6–11 months, 12–23 months, and 2–4 years, followed by 5-year intervals up to 80+ years), sex, and region. Because this study did not involve experiments with investigator-determined sample sizes or prospective participant recruitment, no a priori sample size calculation was performed; sample size was determined by the scope and availability of the GBD 2023 estimation framework. The inclusion of the complete time series (1990–2023) and near-complete global geographic coverage provides sufficient information for stable estimation and regional comparisons, and uncertainty was quantified using 1,000 GBD posterior draws (reported as 95% uncertainty intervals). Detailed methods are described in the corresponding GBD 2023 capstone publications (https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(25)01637-X/fulltext). |
| Data exclusions | In this study, data inclusion and exclusion criteria were determined by the GBD 2023 modelling framework, data availability, and requirements for global comparability. Potential covariates were excluded if they were not consistently available across all analysed locations and years. For mortality estimation, locations without sufficient cause-of-death data were not included in the data-rich Cause of Death Ensemble model (CODEm) pathway and were instead estimated using the natural history model. For incidence estimation, when notified WHO Joint Reporting Form surveillance cases exceeded modelled incidence estimates for a given location-year, the empirical notification count was used for that location-year to avoid estimating fewer cases than were reported. |
| Replication | Experimental replication was not applicable because this study involved secondary analysis of population-level estimates rather than experimental data. All eligible GBD locations and years were included, and uncertainty was propagated using 1,000 draws. |
| Randomization | Randomization was not relevant to this study. This analysis is an observational mapping study and there were no experimental groups. |
| Blinding | Blinding was not relevant to this study, as it was an observational study using survey and surveillance data. |

# Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

## Materials & experimental systems

| n/a | Involved in the study |
|---|---|
| ☒ | ☐ Antibodies |
| ☒ | ☐ Eukaryotic cell lines |
| ☒ | ☐ Palaeontology and archaeology |
| ☒ | ☐ Animals and other organisms |
| ☒ | ☐ Clinical data |
| ☒ | ☐ Dual use research of concern |
| ☒ | ☐ Plants |

## Methods

| n/a | Involved in the study |
|---|---|
| ☒ | ☐ ChIP-seq |
| ☒ | ☐ Flow cytometry |
| ☒ | ☐ MRI-based neuroimaging |

## Plants

| | |
|---|---|
| Seed stocks | Not applicable |
| Novel plant genotypes | Not applicable |
| Authentication | Not applicable |