# Mortality from snakebite envenomation: an analysis from the Global Burden of Disease Study 2019

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# Abstract

Venomous snakebite is an important cause of preventable death. The World Health Organization (WHO) set a goal to halve snakebite mortality by 2030. We used verbal autopsy and vital registration data to model the proportion of venomous animal deaths due to snakes by location, age, year, and sex, and applied these proportions to venomous animal contact mortality estimates from the Global Burden of Disease 2019 study. In 2019, 63,400 people (95% uncertainty interval 38,900–78,600) died globally from snakebites, which was equal to an age-standardized mortality rate (ASMR) of 0.8 deaths (0.5–1.0) per 100,000 and represents a 36% (2–49) decrease in ASMR since 1990. India had the greatest number of deaths in 2019, equal to an ASMR of 4.0 per 100,000 (2.3-5.0). We forecast mortality will continue to decline, but not sufficiently to meet the WHO's goals. Improved data collection should be prioritized to help target interventions, improve burden estimation, and monitor progress.


# Introduction

Venomous snakebites affect millions of people worldwide annually and are a significant source of mortality.[1] Preventing and treating the problem is complex and requires collaboration among the fields of public health, medicine, ecology, and laboratory science. After being removed from the category A neglected tropical disease (NTD) list in 2013, venomous snakebite was reinstated in 2017 in response to antivenom shortages and advocacy from researchers and international NGOs.[2,3] In 2019, the World Health Organization (WHO) set a target to halve the number of deaths and cases of venomous snakebite by 2030.[4]

Few studies on the global disease burden of venomous snakebites have been conducted. In 1998, Chippaux estimated over 100,000 deaths were caused by venomous snakebites.[5] In 2008, Kasturiratne and colleagues used the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) framework to capture regional trends and found that venomous snakebites total between 20,000 and 94,000 annual deaths globally.[6] While both studies were formative in establishing venomous snakebite as an underappreciated cause of death, the studies relied on fragmentary literature reviews and highly heterogeneous data sources. Updated estimates of the global situation are lacking.

Regional meta-analyses have also been conducted in sub-Saharan Africa and the Americas using national health reporting systems, hospital records, and household surveys.[7,8] In India, verbal autopsy surveys, which are interviews that retrospectively ascertain the cause of death and can be scaled up to the population level, have been used to estimate the mortality burden in detail.[9,10] Each of these studies has shown venomous snakebites to be a major source of disease burden.

The GBD is a major effort to collect and incorporate all available data for 369 causes of disease and injury and 87 risk factors from published literature, registries, vital registration systems, verbal autopsies, and hospital records to produce comparable estimates of burden at the global, regional, and national levels.[11] We used the GBD's data repository and modelling tools built for disease burden research to quantify the mortality and years of life lost (YLLs) due to venomous snakebites in 204 countries and territories from 1990 to 2019 by age and sex, as well as make forecasts of the disease burden to 2050. We also explored associations between venomous snakebite mortality and select covariates to better understand what factors influence venomous snakebite death.

# Results

Global mortality and years of life lost

Venomous snakebites accounted for 63,400 deaths (95% uncertainty interval [UI] 38,900–78,600) and 2.94 million years of life lost (YLLs) (1.79 million–3.74 million) in 2019, globally (Table 1). This was equal to an age-standardized rate of 0.81 deaths (0.5–1.0) per 100,000 and 38 YLLs (23 to 49) per 100,000. From 1990 to 2019, the global age-standardized rate of death and YLLs per 100,000 decreased significantly by 36% (2–49) and 40% (6–55), respectively. Globally, venomous snakebite mortality was greater in males than females in 2019, although non-significantly, with an age-standardized rate of 0.9 deaths (0.6–1.1) per 100,000, compared to 0.7 deaths (0.3–1.0) per 100,000 in females (Figure 2).

Table 1
Deaths and years of life lost (YLLs) due to venomous snakebites in 2019 at the global, regional, and national level.

| | | Deaths | | | YLLs | | |
|---|---|---|---|---|---|---|---|
| **Location** | **Endemic venomous snakes** | **Count, 2019** | **Age-standardized rate per 100,000, 2019** | **Percent change from 1990 to 2019** | **Count, 2019** | **Age-standardized rate per 100,000, 2019** | **Percent change from 1990 to 2019** |
| **Global** | | **63,400 (38,900 to 78,600)** | **0.81 (0.50 to 1)** | **-36% (-49% to -2%)** | **2,940,000 (1,790,000 to 3,740,000)** | **38.35 (23.30 to 49.15)** | **-40% (-55% to -6%)** |
| **Central Asia** | | **8.9 (7.7 to 10)** | **0.01 (0.01 to 0.01)** | **-43% (-55% to -30%)** | **461 (396 to 536)** | **0.49 (0.42 to 0.57)** | **-48% (-60% to -34%)** |
| Armenia | Yes | <1 (<1 to <1) | 0.02 (0.01 to 0.02) | -49% (-64% to -24%) | 25 (20 to 32) | 0.86 (0.68 to 1.11) | -53% (-68% to -22%) |
| Azerbaijan | Yes | <1 (<1 to <1) | 0.01 (<0.01 to 0.01) | -32% (-57–7%) | 37 (22 to 54) | 0.33 (0.21 to 0.48) | -34% (-59–4%) |
| Georgia | Yes | <1 (<1 to <1) | 0.01 (<0.01 to 0.01) | -25% (-51–13%) | 11 (7.8 to 15) | 0.27 (0.20 to 0.37) | -32% (-57–7%) |
| Kazakhstan | Yes | 2.5 (1.9 to 3.3) | 0.01 (0.01 to 0.02) | -40% (-59% to -15%) | 114 (87 to 147) | 0.60 (0.46 to 0.77) | -44% (-62% to -22%) |
| Kyrgyzstan | Yes | <1 (<1 to <1) | 0.01 (0.01 to 0.01) | -54% (-69% to -30%) | 41 (31 to 53) | 0.60 (0.45 to 0.77) | -59% (-73% to -35%) |
| Mongolia | Yes | <1 (<1 to <1) | 0.01 (0.01 to 0.01) | -56% (-88–42%) | 24 (12 to 38) | 0.64 (0.32 to 1.02) | -61% (-90–33%) |
| Tajikistan | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | -42% (-67–3%) | 22 (16 to 31) | 0.22 (0.16 to 0.29) | -48% (-74–1%) |
| Turkmenistan | Yes | <1 (<1 to <1) | 0.01 (0.01 to 0.02) | 5% (-32–59%) | 38 (28 to 53) | 0.72 (0.54 to 0.99) | -8% (-43–45%) |
| Uzbekistan | Yes | 2.8 (2.2 to 3.6) | 0.01 (0.01 to 0.01) | -35% (-59% to -8%) | 148 (115 to 191) | 0.43 (0.34 to 0.55) | -42% (-63% to -15%) |

| | | Deaths | | | YLLs | | |
|---|---|---|---|---|---|---|---|
| **Central Europe** | | **5.3 (4.4 to 6.4)** | **<0.01 (<0.01 to <0.01)** | **-44% (-53% to -33%)** | **190 (158 to 230)** | **0.15 (0.13 to 0.18)** | **-47% (-56% to -36%)** |
| Albania | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | -62% (-75% to -41%) | 2.2 (1.7 to 3.1) | 0.10 (0.07 to 0.14) | -57% (-73% to -32%) |
| Bosnia and Herzegovina | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | -41% (-61% to -16%) | 2.8 (2 to 3.7) | 0.09 (0.07 to 0.12) | -39% (-58% to -15%) |
| Bulgaria | Yes | <1 (<1 to 1.3) | 0.01 (0.01 to 0.01) | -2% (-30–33%) | 25 (17 to 37) | 0.31 (0.22 to 0.43) | -15% (-43–21%) |
| Croatia | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | -3% (-36–39%) | 6.4 (4.4 to 8.8) | 0.16 (0.11 to 0.22) | -18% (-47–19%) |
| Czechia | Yes | 1.2 (<1 to 1.6) | 0.01 (0.01 to 0.01) | -61% (-73% to -45%) | 42 (31 to 57) | 0.31 (0.23 to 0.41) | -61% (-73% to -45%) |
| Hungary | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | -34% (-55% to -7%) | 18 (13 to 24) | 0.17 (0.12 to 0.22) | -37% (-57% to -8%) |
| Montenegro | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | -33% (-50% to -9%) | <1 (<1 to <1) | 0.06 (0.05 to 0.08) | -36% (-54% to -14%) |
| North Macedonia | Yes | <1 (<1 to <1) | <0.01 (<0.01 to 0.01) | -18% (-45–17%) | 4.6 (3.1 to 6.5) | 0.19 (0.13 to 0.26) | -22% (-48–11%) |
| Poland | Yes | <1 (<1 to 1.1) | <0.01 (<0.01 to <0.01) | -56% (-65% to -46%) | 32 (26 to 39) | 0.08 (0.07 to 0.10) | -57% (-65% to -47%) |
| Romania | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | -28% (-52–1%) | 28 (19 to 38) | 0.14 (0.10 to 0.18) | -34% (-55% to -8%) |
| Serbia | Yes | <1 (<1 to <1) | <0.01 (<0.01 to 0.01) | -45% (-68% to -12%) | 17 (12 to 25) | 0.17 (0.12 to 0.25) | -49% (-71% to -20%) |
| Slovakia | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | -41% (-62% to -6%) | 10 (7 to 14) | 0.17 (0.12 to 0.24) | -42% (-63% to -7%) |

| | | Deaths | | | YLLs | | |
|---|---|---|---|---|---|---|---|
| Slovenia | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | 3% (-31–47%) | 1.6 (1.2 to 2.2) | 0.08 (0.06 to 0.11) | -6% (-34–34%) |
| **Eastern Europe** | | **22 (19 to 26)** | **0.01 (0.01 to 0.01)** | **-49% (-56% to -42%)** | **919 (789 to 1,070)** | **0.42 (0.36 to 0.48)** | **-52% (-59% to -46%)** |
| Belarus | Yes | 1.2 (<1 to 1.8) | 0.01 (0.01 to 0.01) | -38% (-62% to -7%) | 49 (32 to 71) | 0.46 (0.31 to 0.66) | -42% (-63% to -12%) |
| Estonia | Yes | <1 (<1 to <1) | 0.01 (<0.01 to 0.01) | 40% (-16–122%) | 3.7 (2.3 to 5.7) | 0.21 (0.14 to 0.33) | 24% (-24–90%) |
| Latvia | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | -72% (-81% to -59%) | 1.1 (<1 to 1.4) | 0.06 (0.05 to 0.08) | -74% (-83% to -60%) |
| Lithuania | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | 7% (-29–54%) | 4.7 (3.4 to 6.5) | 0.16 (0.12 to 0.22) | -20% (-47–14%) |
| Republic of Moldova | Yes | <1 (<1 to <1) | <0.01 (<0.01 to 0.01) | -6% (-33–28%) | 7.4 (5.6 to 9.7) | 0.23 (0.17 to 0.31) | 1% (-32–45%) |
| Russian Federation | Yes | 16 (13 to 19) | 0.01 (0.01 to 0.01) | -57% (-63% to -50%) | 651 (549 to 774) | 0.43 (0.36 to 0.50) | -60% (-66% to -53%) |
| Ukraine | Yes | 4.5 (3.2 to 6.2) | 0.01 (0.01 to 0.01) | -15% (-42–23%) | 202 (144 to 283) | 0.44 (0.32 to 0.59) | -14% (-40–24%) |
| **Australasia** | | **1.3 (1.0 to 1.7)** | **<0.01 (<0.01 to <0.01)** | **-54% (-66% to -40%)** | **52 (40 to 65)** | **0.17 (0.14 to 0.22)** | **-55% (-67% to -39%)** |
| Australia | Yes | 1.3 (1.0 to 1.7) | <0.01 (<0.01 to 0.01) | -55% (-66% to -41%) | 52 (40 to 65) | 0.20 (0.16 to 0.26) | -55% (-67% to -40%) |
| New Zealand | No | – | – | – | – | – | – |
| **High-income Asia Pacific** | | **8.8 (6.7 to 11)** | **<0.01 (<0.01 to <0.01)** | **-73% (-79% to -67%)** | **205 (161 to 249)** | **0.09 (0.07 to 0.10)** | **-69% (-76% to -63%)** |

| | | Deaths | | | YLLs | | |
|---|---|---|---|---|---|---|---|
| Brunei Darussalam | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | -63% (-76% to -41%) | <1 (<1 to <1) | 0.11 (0.08 to 0.14) | -63% (-77% to -43%) |
| Japan | Yes | 2.4 (2.0 to 2.7) | <0.01 (<0.01 to <0.01) | -83% (-85% to -82%) | 55 (51 to 59) | 0.04 (0.04 to 0.04) | -75% (-77% to -73%) |
| Republic of Korea | Yes | 6.4 (4.2 to 8.3) | 0.01 (0.01 to 0.01) | -70% (-81% to -57%) | 147 (100 to 191) | 0.21 (0.15 to 0.26) | -73% (-82% to -63%) |
| Singapore | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | -58% (-66% to -50%) | 2.6 (2.2 to 3.1) | 0.05 (0.04 to 0.06) | -56% (-64% to -46%) |
| **High-income North America** | | **17 (16 to 19)** | **<0.01 (<0.01 to <0.01)** | **-17% (-24% to -10%)** | **627 (585 to 678)** | **0.16 (0.15 to 0.17)** | **-19% (-25% to -13%)** |
| Canada | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | -20% (-41–5%) | 32 (26 to 41) | 0.09 (0.07 to 0.11) | -22% (-42–0%) |
| Greenland | No | – | – | – | – | – | – |
| United States of America | Yes | 17 (15 to 18) | <0.01 (<0.01 to <0.01) | -17% (-23% to -9%) | 595 (555 to 646) | 0.17 (0.16 to 0.18) | -19% (-25% to -12%) |
| **Southern Latin America** | | **3.3 (2.7 to 3.9)** | **<0.01 (<0.01 to 0.01)** | **171% (108–246%)** | **136 (110 to 164)** | **0.21 (0.17 to 0.26)** | **173% (104–255%)** |
| Argentina | Yes | 3.2 (2.6 to 3.8) | 0.01 (0.01 to 0.01) | 179% (111–257%) | 132 (106 to 161) | 0.30 (0.24 to 0.37) | 172% (102–255%) |
| Chile | No | – | – | – | – | – | – |
| Uruguay | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | 151% (99–214%) | 3.2 (2.6 to 4) | 0.10 (0.08 to 0.12) | 105% (57–170%) |
| **Western Europe** | | **14 (12 to 15)** | **<0.01 (<0.01 to <0.01)** | **-20% (-28% to -11%)** | **459 (422 to 502)** | **0.10 (0.09 to 0.11)** | **-23% (-31% to -15%)** |
| Andorra | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | -26% (-54–9%) | <1 (<1 to <1) | 0.09 (0.06 to 0.12) | -24% (-53–11%) |

| | | Deaths | | | YLLs | | |
|---|---|---|---|---|---|---|---|
| Austria | Yes | <1 (<1 to <1) | <0.01 (<0.01 to 0.01) | -17% (-39–10%) | 20 (16 to 25) | 0.21 (0.17 to 0.26) | -25% (-44% to -1%) |
| Belgium | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | 53% (20–90%) | 9.5 (7.8 to 12) | 0.09 (0.07 to 0.10) | 30% (1–62%) |
| Cyprus | Yes | <1 (<1 to <1) | <0.01 (<0.01 to 0.01) | -53% (-68% to -34%) | 1.8 (1.5 to 2.2) | 0.15 (0.12 to 0.18) | -46% (-63% to -27%) |
| Denmark | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | 53% (18–95%) | 1.8 (1.5 to 2.2) | 0.03 (0.03 to 0.04) | 40% (8–81%) |
| Finland | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | -58% (-71% to -40%) | 1.9 (1.5 to 2.4) | 0.04 (0.03 to 0.05) | -56% (-68% to -40%) |
| France | Yes | 2.3 (1.8 to 2.9) | <0.01 (<0.01 to <0.01) | -44% (-58% to -22%) | 75 (60 to 94) | 0.10 (0.09 to 0.13) | -43% (-57% to -25%) |
| Germany | Yes | 2.5 (2.0 to 3.2) | <0.01 (<0.01 to <0.01) | -20% (-41–7%) | 88 (70 to 112) | 0.10 (0.08 to 0.12) | -21% (-39–3%) |
| Greece | Yes | <1 (<1 to <1) | <0.01 (<0.01 to 0.01) | 47% (9–92%) | 21 (16 to 26) | 0.17 (0.14 to 0.21) | 35% (3–75%) |
| Iceland | No | – | – | – | – | – | – |
| Ireland | No | – | – | – | – | – | – |
| Israel | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | -47% (-57% to -33%) | 8 (6.8 to 9.5) | 0.09 (0.07 to 0.10) | -45% (-57% to -31%) |
| Italy | Yes | 2.8 (2.6 to 3.1) | <0.01 (<0.01 to <0.01) | -32% (-39% to -26%) | 93 (86 to 101) | 0.15 (0.13 to 0.16) | -33% (-39% to -27%) |
| Luxembourg | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | -65% (-75% to -53%) | <1 (<1 to <1) | 0.07 (0.05 to 0.09) | -56% (-69% to -38%) |
| Malta | No | – | – | – | – | – | – |
| Monaco | No | – | – | – | – | – | – |

| | | Deaths | | | YLLs | | |
|---|---|---|---|---|---|---|---|
| Netherlands | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | -46% (-58% to -32%) | 4.2 (3.5 to 4.9) | 0.03 (0.02 to 0.03) | -46% (-58% to -30%) |
| Norway | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | -16% (-30–0%) | <1 (<1 to 1.1) | 0.05 (0.05 to 0.06) | -26% (-40% to -12%) |
| Portugal | Yes | 1.0 (<1 to 1.3) | <0.01 (<0.01 to 0.01) | 114% (65–174%) | 21 (18 to 26) | 0.16 (0.13 to 0.19) | 38% (4–75%) |
| San Marino | Yes | <1 (<1 to <1) | <0.01 (<0.01 to 0.01) | -17% (-53–34%) | <1 (<1 to <1) | 0.20 (0.13 to 0.32) | -24% (-55–26%) |
| Spain | Yes | 1.9 (1.5 to 2.3) | <0.01 (<0.01 to <0.01) | 13% (-11–44%) | 67 (55 to 81) | 0.15 (0.12 to 0.17) | 8% (-13–35%) |
| Sweden | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | -6% (-33–28%) | 4.9 (4 to 6.1) | 0.05 (0.04 to 0.06) | -11% (-33–16%) |
| Switzerland | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | 67% (26–114%) | 13 (10 to 16) | 0.15 (0.12 to 0.17) | 49% (16–88%) |
| United Kingdom | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | -4% (-20–15%) | 28 (25 to 33) | 0.05 (0.04 to 0.05) | -7% (-23–14%) |
| **Andean Latin America** | | **47 (16 to 60)** | **0.08 (0.03 to 0.10)** | **54% (-65–122%)** | **1,920 (636 to 2,470)** | **3.11 (1.03 to 4.01)** | **31% (-69–96%)** |
| Bolivia (Plurinational State of) | Yes | 14 (5.2 to 20) | 0.15 (0.05 to 0.21) | 27% (-60–103%) | 535 (203 to 742) | 4.89 (1.85 to 6.84) | 0% (-68–69%) |
| Ecuador | Yes | 24 (5.7 to 33) | 0.15 (0.03 to 0.20) | 478% (-64–711%) | 1,000 (246 to 1,350) | 5.85 (1.44 to 7.86) | 451% (-66–669%) |
| Peru | Yes | 9.4 (4.6 to 14) | 0.03 (0.01 to 0.04) | -37% (-72–1%) | 380 (176 to 552) | 1.14 (0.53 to 1.66) | -47% (-75% to -9%) |
| **Caribbean** | | **12 (9.4 to 15)** | **0.02 (0.02 to 0.03)** | **253% (153–374%)** | **470 (362 to 602)** | **1.00 (0.77 to 1.29)** | **231% (133–343%)** |
| Antigua and Barbuda | No | – | – | – | – | – | – |
| Bahamas | No | – | – | – | – | – | – |

| | | Deaths | | | YLLs | | |
|---|---|---|---|---|---|---|---|
| Barbados | No | – | – | – | – | – | – |
| Belize | Yes | <1 (<1 to 1.1) | 0.27 (0.22 to 0.33) | 444% (302–607%) | 41 (33 to 49) | 10.38 (8.39 to 12.51) | 372% (248–509%) |
| Bermuda | No | – | – | – | – | – | – |
| Cuba | No | – | – | – | – | – | – |
| Dominica | No | – | – | – | – | – | – |
| Dominican Republic | No | – | – | – | – | – | – |
| Grenada | No | – | – | – | – | – | – |
| Guyana | Yes | 8.6 (6.5 to 11) | 1.30 (1.00 to 1.68) | 296% (178–430%) | 341 (256 to 447) | 46.01 (34.64 to 60.33) | 274% (157–407%) |
| Haiti | No | – | – | – | – | – | – |
| Jamaica | No | – | – | – | – | – | – |
| Puerto Rico | No | – | – | – | – | – | – |
| Saint Kitts and Nevis | No | – | – | – | – | – | – |
| Saint Lucia | Yes | <1 (<1 to <1) | 0.16 (0.13 to 0.20) | 297% (215–402%) | 9.6 (7.8 to 12) | 4.93 (4.00 to 5.99) | 270% (190–369%) |
| Saint Vincent and the Grenadines | No | – | – | – | – | – | – |
| Suriname | Yes | 2.0 (<1 to 2.6) | 0.34 (0.12 to 0.44) | 412% (-16–630%) | 69 (27 to 92) | 11.83 (4.70 to 15.67) | 330% (-24–537%) |
| Trinidad and Tobago | Yes | <1 (<1 to <1) | 0.02 (0.01 to 0.02) | 429% (246–660%) | 9.4 (6 to 14) | 0.70 (0.44 to 1.02) | 381% (200–628%) |
| United States Virgin Islands | No | – | – | – | – | – | – |
| **Central Latin America** | | **210 (174 to 255)** | **0.09 (0.07 to 0.11)** | **-66% (-72% to -57%)** | **8,550 (7,020 to 10,500)** | **3.49 (2.87 to 4.29)** | **-74% (-79% to -67%)** |
| Colombia | Yes | 50 (36 to 66) | 0.10 (0.07 to 0.13) | -77% (-83% to -69%) | 2,070 (1,520 to 2,730) | 4.32 (3.17 to 5.69) | -79% (-85% to -71%) |

| | | Deaths | | | YLLs | | |
|---|---|---|---|---|---|---|---|
| Costa Rica | Yes | 3.9 (2.9 to 5.2) | 0.08 (0.06 to 0.10) | -20% (-43–9%) | 121 (88 to 163) | 2.40 (1.75 to 3.24) | -23% (-46–5%) |
| El Salvador | Yes | 1.3 (<1 to 1.9) | 0.02 (0.01 to 0.03) | 222% (-58–401%) | 52 (29 to 77) | 0.88 (0.49 to 1.30) | 150% (-66–300%) |
| Guatemala | Yes | 10 (7.9 to 13) | 0.08 (0.06 to 0.10) | 82% (28–144%) | 470 (345 to 605) | 2.97 (2.22 to 3.79) | 47% (3–103%) |
| Honduras | Yes | 5.3 (3.0 to 8.4) | 0.07 (0.04 to 0.12) | -53% (-71% to -24%) | 226 (135 to 375) | 2.68 (1.59 to 4.33) | -65% (-78% to -43%) |
| Mexico | Yes | 69 (58 to 82) | 0.06 (0.05 to 0.07) | -75% (-79% to -69%) | 2,820 (2,410 to 3,280) | 2.35 (2.02 to 2.74) | -82% (-86% to -78%) |
| Nicaragua | Yes | 7.9 (4.9 to 10) | 0.15 (0.10 to 0.19) | -51% (-65% to -29%) | 363 (214 to 481) | 5.95 (3.53 to 7.88) | -57% (-70% to -38%) |
| Panama | Yes | 14 (11 to 19) | 0.35 (0.26 to 0.46) | -50% (-64% to -31%) | 624 (468 to 823) | 14.96 (11.21 to 19.81) | -50% (-64% to -32%) |
| Venezuela (Bolivarian Republic of) | Yes | 48 (34 to 66) | 0.17 (0.12 to 0.23) | -19% (-45–16%) | 1,800 (1,270 to 2,470) | 6.31 (4.48 to 8.60) | -21% (-46–10%) |
| **Tropical Latin America** | | **240 (224 to 261)** | **0.11 (0.10 to 0.12)** | **-58% (-62% to -51%)** | **8,550 (7,860 to 9,440)** | **3.86 (3.51 to 4.30)** | **-65% (-70% to -58%)** |
| Brazil | Yes | 233 (218 to 253) | 0.11 (0.10 to 0.12) | -58% (-63% to -52%) | 8,290 (7,630 to 9,140) | 3.86 (3.53 to 4.31) | -66% (-71% to -59%) |
| Paraguay | Yes | 6.3 (1.9 to 9) | 0.10 (0.03 to 0.15) | 133% (-56–251%) | 258 (78 to 367) | 3.92 (1.19 to 5.54) | 107% (-60–214%) |
| **North Africa and Middle East** | | **350 (243 to 485)** | **0.06 (0.05 to 0.09)** | **-62% (-74% to -34%)** | **20,500 (14,400 to 28,400)** | **3.38 (2.39 to 4.68)** | **-65% (-79% to -34%)** |
| Afghanistan | Yes | 110 (70 to 189) | 0.34 (0.22 to 0.57) | -40% (-64% to -2%) | 6,710 (4,260 to 11,800) | 17.78 (11.19 to 30.34) | -43% (-69% to -3%) |

| | | Deaths | | | YLLs | | |
|---|---|---|---|---|---|---|---|
| Algeria | Yes | 9.4 (6.3 to 14) | 0.03 (0.02 to 0.04) | -69% (-79% to -51%) | 374 (241 to 554) | 0.96 (0.63 to 1.41) | -78% (-86% to -62%) |
| Bahrain | Yes | <1 (<1 to <1) | 0.02 (0.01 to 0.03) | -50% (-70% to -20%) | 6.0 (3.9 to 8.4) | 0.54 (0.37 to 0.72) | -62% (-76% to -39%) |
| Egypt | Yes | 10 (5.6 to 20) | 0.01 (0.01 to 0.02) | -75% (-88% to -49%) | 693 (299 to 1,520) | 0.66 (0.33 to 1.43) | -80% (-90% to -56%) |
| Iran (Islamic Republic of) | Yes | 42 (26 to 49) | 0.06 (0.04 to 0.07) | -78% (-84% to -66%) | 1,970 (1,110 to 2,470) | 2.53 (1.44 to 3.18) | -83% (-89% to -71%) |
| Iraq | Yes | 13 (9.4 to 18) | 0.04 (0.03 to 0.05) | -62% (-79% to -33%) | 794 (549 to 1,080) | 1.81 (1.28 to 2.44) | -71% (-85% to -46%) |
| Jordan | Yes | 2.1 (1.6 to 2.7) | 0.04 (0.02 to 0.05) | -48% (-65% to -25%) | 108 (71 to 149) | 1.07 (0.71 to 1.40) | -60% (-74% to -38%) |
| Kuwait | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | -72% (-80% to -61%) | 3.2 (2.5 to 4.1) | 0.07 (0.06 to 0.09) | -75% (-83% to -64%) |
| Lebanon | Yes | <1 (<1 to 1.3) | 0.01 (0.01 to 0.03) | -71% (-83% to -51%) | 21 (11 to 41) | 0.43 (0.22 to 0.84) | -75% (-85% to -59%) |
| Libya | Yes | 2.2 (1.4 to 3.0) | 0.04 (0.03 to 0.06) | -59% (-76% to -31%) | 92 (57 to 131) | 1.61 (0.99 to 2.32) | -69% (-83% to -42%) |
| Morocco | Yes | 17 (7.1 to 44) | 0.06 (0.02 to 0.14) | -47% (-68% to -1%) | 625 (282 to 1,540) | 1.85 (0.83 to 4.5) | -59% (-78% to -19%) |
| Oman | Yes | <1 (<1 to <1) | 0.02 (0.01 to 0.03) | -58% (-79% to -26%) | 12 (8.9 to 16) | 0.42 (0.31 to 0.56) | -67% (-82% to -38%) |
| Palestine | Yes | <1 (<1 to <1) | 0.02 (0.01 to 0.03) | -53% (-69% to -29%) | 28 (17 to 39) | 0.64 (0.39 to 0.83) | -68% (-81% to -43%) |

| | | Deaths | | | YLLs | | |
|---|---|---|---|---|---|---|---|
| Qatar | Yes | <1 (<1 to <1) | <0.01 (<0.01 to <0.01) | -67% (-85% to -36%) | 1.4 (1 to 2.3) | 0.07 (0.05 to 0.12) | -74% (-87% to -54%) |
| Saudi Arabia | Yes | 9.8 (6.9 to 13) | 0.06 (0.04 to 0.07) | -44% (-69% to -6%) | 387 (272 to 534) | 1.48 (0.98 to 1.98) | -60% (-76% to -29%) |
| Sudan | Yes | 86 (44 to 132) | 0.24 (0.12 to 0.34) | -66% (-81% to -34%) | 5,830 (2,940 to 9,150) | 12.35 (6.27 to 18.83) | -71% (-86% to -33%) |
| Syrian Arab Republic | Yes | 2.1 (1.5 to 2.9) | 0.02 (0.01 to 0.02) | -79% (-88% to -64%) | 109 (75 to 153) | 0.79 (0.55 to 1.13) | -84% (-91% to -71%) |
| Tunisia | Yes | 2.2 (1.4 to 3.5) | 0.02 (0.01 to 0.03) | -72% (-82% to -55%) | 83 (51 to 138) | 0.75 (0.46 to 1.24) | -80% (-88% to -64%) |
| Turkey | Yes | 3.6 (2.6 to 5.4) | <0.01 (<0.01 to 0.01) | -90% (-94% to -81%) | 150 (110 to 223) | 0.21 (0.15 to 0.32) | -91% (-95% to -82%) |
| United Arab Emirates | Yes | 2.8 (1.2 to 5.1) | 0.05 (0.02 to 0.08) | -75% (-89% to -56%) | 129 (57 to 232) | 1.53 (0.74 to 2.47) | -81% (-92% to -66%) |
| Yemen | Yes | 36 (21 to 61) | 0.14 (0.09 to 0.24) | -54% (-73% to -20%) | 2,320 (1,330 to 3,900) | 6.68 (3.96 to 11.20) | -60% (-79% to -18%) |
| **South Asia** | | **54,600 (31,800 to 68,300)** | **3.37 (1.96 to 4.19)** | **-43% (-56% to -12%)** | **2,540,000 (1,480,000 to 3,210,000)** | **143.68 (83.05 to 182.25)** | **-47% (-60% to -17%)** |
| Bangladesh | Yes | 1,170 (377 to 1,530) | 0.78 (0.26 to 1.01) | -47% (-64% to -23%) | 61,900 (19,000 to 83,200) | 39.03 (12.03 to 52.33) | -45% (-65% to -19%) |
| Bhutan | Yes | 8.3 (5.6 to 12) | 1.28 (0.87 to 1.79) | -35% (-64–36%) | 434 (271 to 652) | 62.15 (39.19 to 93.61) | -38% (-72–58%) |
| India | Yes | 51,100 (29,600 to 64,100) | 4.00 (2.31 to 5.01) | -45% (-57% to -14%) | 2,340,000 (1,350,000 to 2,970,000) | 171.40 (99.04 to 217.65) | -48% (-61% to -17%) |

| | | Deaths | | | YLLs | | |
|---|---|---|---|---|---|---|---|
| Nepal | Yes | 234 (157 to 348) | 0.90 (0.61 to 1.32) | -42% (-65–5%) | 10,700 (7,290 to 16,400) | 36.42 (24.48 to 55.03) | -52% (-72% to -12%) |
| Pakistan | Yes | 2,070 (1,470 to 2,950) | 1.06 (0.74 to 1.49) | -1% (-27–46%) | 123,000 (87,700 to 179,000) | 52.87 (37.67 to 75.72) | 0% (-27–49%) |
| **East Asia** | | **230 (176 to 280)** | **0.01 (0.01 to 0.01)** | **-84% (-88% to -67%)** | **6,840 (5,270 to 8,270)** | **0.40 (0.31 to 0.47)** | **-88% (-91% to -72%)** |
| China | Yes | 223 (170 to 273) | 0.01 (0.01 to 0.01) | -84% (-89% to -67%) | 6,600 (5,070 to 8,040) | 0.40 (0.31 to 0.48) | -88% (-92% to -72%) |
| Democratic People's Republic of Korea | Yes | 6.0 (2.8 to 11) | 0.02 (0.01 to 0.04) | -44% (-70% to -4%) | 199 (94 to 366) | 0.67 (0.33 to 1.22) | -53% (-76% to -15%) |
| Taiwan (Province of China) | Yes | 1.2 (<1 to 1.7) | <0.01 (<0.01 to 0.01) | -54% (-71% to -32%) | 38 (26 to 56) | 0.12 (0.09 to 0.18) | -55% (-71% to -31%) |
| **Oceania** | | **69 (40 to 108)** | **0.65 (0.38 to 1.03)** | **-14% (-38–18%)** | **4,110 (2,300 to 6,380)** | **30.60 (17.47 to 47.81)** | **-16% (-42–19%)** |
| American Samoa | No | – | – | – | – | – | – |
| Cook Islands | No | – | – | – | – | – | – |
| Fiji | No | – | – | – | – | – | – |
| Guam | No | – | – | – | – | – | – |
| Kiribati | No | – | – | – | – | – | – |
| Marshall Islands | No | – | – | – | – | – | – |
| Micronesia (Federated States of) | No | – | – | – | – | – | – |
| Nauru | No | – | – | – | – | – | – |
| Niue | No | – | – | – | – | – | – |
| Northern Mariana Islands | No | – | – | – | – | – | – |

| | | Deaths | | | YLLs | | |
|---|---|---|---|---|---|---|---|
| Palau | No | – | – | – | – | – | – |
| Papua New Guinea | Yes | 69 (40 to 108) | 0.89 (0.52 to 1.41) | -22% (-44–6%) | 4,110 (2,300 to 6,380) | 39.71 (22.60 to 61.72) | -27% (-49–4%) |
| Samoa | No | – | – | – | – | – | – |
| Solomon Islands | No | – | – | – | – | – | – |
| Tokelau | No | – | – | – | – | – | – |
| Tonga | No | – | – | – | – | – | – |
| Tuvalu | No | – | – | – | – | – | – |
| Vanuatu | No | – | – | – | – | – | – |
| **Southeast Asia** | | **801 (581 to 961)** | **0.14 (0.10 to 0.16)** | **-66% (-75% to -49%)** | **36,700 (24,700 to 46,500)** | **5.96 (3.85 to 7.61)** | **-70% (-81% to -53%)** |
| Cambodia | Yes | 1.7 (<1 to 2.8) | 0.01 (0.01 to 0.02) | -12% (-60–62%) | 106 (52 to 182) | 0.59 (0.29 to 1.00) | -5% (-59–83%) |
| Indonesia | Yes | 149 (91 to 185) | 0.09 (0.04 to 0.11) | -54% (-67% to -32%) | 5,720 (3,990 to 7,260) | 2.50 (1.65 to 3.15) | -72% (-81% to -55%) |
| Lao People's Democratic Republic | Yes | 21 (9 to 39) | 0.36 (0.15 to 0.63) | -62% (-78% to -33%) | 1,180 (481 to 2,170) | 16.55 (6.87 to 29.97) | -67% (-82% to -38%) |
| Malaysia | Yes | 36 (25 to 48) | 0.14 (0.10 to 0.19) | -37% (-59% to -3%) | 1,050 (760 to 1,400) | 3.62 (2.59 to 4.79) | -48% (-66% to -21%) |
| Maldives | No | – | – | – | – | – | – |
| Mauritius | No | – | – | – | – | – | – |
| Myanmar | Yes | 171 (107 to 251) | 0.34 (0.22 to 0.50) | -51% (-81–22%) | 11,600 (5,680 to 18,200) | 22.82 (10.94 to 35.74) | -48% (-83–47%) |
| Philippines | Yes | 91 (67 to 108) | 0.10 (0.07 to 0.11) | -63% (-71% to -50%) | 4,600 (3,410 to 5,410) | 4.15 (3.10 to 4.88) | -68% (-76% to -54%) |
| Seychelles | No | – | – | – | – | – | – |

| | | Deaths | | | YLLs | | |
|---|---|---|---|---|---|---|---|
| Sri Lanka | Yes | 52 (37 to 72) | 0.22 (0.16 to 0.31) | -75% (-84% to -52%) | 2,220 (1,580 to 3,110) | 10.01 (7.17 to 13.95) | -79% (-86% to -57%) |
| Thailand | Yes | 134 (98 to 184) | 0.16 (0.12 to 0.21) | -78% (-84% to -69%) | 4,810 (3,550 to 6,650) | 6.46 (4.90 to 8.58) | -83% (-88% to -73%) |
| Timor-Leste | Yes | 1.7 (1.0 to 2.4) | 0.16 (0.10 to 0.22) | -63% (-80% to -24%) | 89 (49 to 131) | 6.66 (3.91 to 9.68) | -70% (-87% to -35%) |
| Viet Nam | Yes | 143 (71 to 192) | 0.16 (0.08 to 0.22) | -65% (-78% to -43%) | 5,330 (2,500 to 7,340) | 6.27 (2.69 to 8.81) | -69% (-82% to -46%) |
| **Central Sub-Saharan Africa** | | **791 (507 to 1,350)** | **1.25 (0.83 to 1.82)** | **-18% (-44–26%)** | **34,200 (19,900 to 72,100)** | **37.19 (23.85 to 61.58)** | **-27% (-51–15%)** |
| Angola | Yes | 87 (54 to 148) | 0.65 (0.42 to 1.07) | -53% (-75% to -6%) | 3,790 (2,100 to 7,480) | 18.79 (11.78 to 31.72) | -59% (-78% to -15%) |
| Central African Republic | Yes | 97 (59 to 159) | 3.44 (2.05 to 5.55) | 35% (-12–122%) | 4,570 (2,700 to 7,760) | 113.61 (68.60 to 186.08) | 31% (-17–108%) |
| Congo | Yes | 40 (26 to 56) | 1.37 (0.92 to 1.88) | -9% (-39–41%) | 1,540 (972 to 2,330) | 39.90 (26.61 to 56.39) | -18% (-47–27%) |
| Democratic Republic of the Congo | Yes | 545 (313 to 1,030) | 1.29 (0.79 to 2.01) | -11% (-42–41%) | 23,500 (11,800 to 56,400) | 38.23 (21.92 to 70.89) | -20% (-51–29%) |
| Equatorial Guinea | Yes | 5.7 (3.2 to 10) | 1.09 (0.57 to 1.92) | -63% (-83% to -21%) | 234 (127 to 468) | 29.33 (15.81 to 54.07) | -70% (-87% to -34%) |
| Gabon | Yes | 17 (9.7 to 26) | 1.54 (0.83 to 2.28) | -15% (-43–26%) | 593 (351 to 979) | 43.64 (25.71 to 68.42) | -24% (-49–10%) |
| **Eastern Sub-Saharan Africa** | | **2,100 (1,570 to 3,000)** | **1.19 (0.83 to 1.61)** | **-36% (-51% to -16%)** | **81,700 (60,300 to 127,000)** | **31.95 (23.78 to 46.08)** | **-41% (-56% to -18%)** |
| Burundi | Yes | 102 (52 to 170) | 1.83 (0.93 to 2.90) | -30% (-57–20%) | 4,190 (2,210 to 7,400) | 52.10 (26.98 to 86.94) | -35% (-61–19%) |

| | | Deaths | | | YLLs | | |
|---|---|---|---|---|---|---|---|
| Comoros | No | – | – | – | – | – | – |
| Djibouti | Yes | 7.1 (3.9 to 11) | 1.22 (0.70 to 1.97) | -9% (-46–42%) | 241 (132 to 402) | 30.20 (17.01 to 48.97) | -18% (-50–30%) |
| Eritrea | Yes | 73 (32 to 132) | 2.87 (1.21 to 5.20) | -19% (-51–42%) | 2,820 (1,290 to 5,300) | 76.33 (33.13 to 138.87) | -28% (-56–21%) |
| Ethiopia | Yes | 499 (321 to 708) | 1.07 (0.63 to 1.52) | -62% (-78% to -39%) | 18,600 (12,900 to 26,700) | 27.85 (17.78 to 39.88) | -65% (-79% to -43%) |
| Kenya | Yes | 349 (197 to 603) | 1.63 (0.92 to 2.74) | -11% (-32–19%) | 12,000 (6,700 to 20,900) | 40.97 (23.14 to 71.03) | -16% (-37–13%) |
| Madagascar | No | – | – | – | – | – | – |
| Malawi | Yes | 69 (47 to 99) | 0.92 (0.64 to 1.27) | -32% (-57–7%) | 2,670 (1,740 to 4,170) | 24.42 (16.33 to 35.22) | -41% (-64% to -4%) |
| Mozambique | Yes | 102 (60 to 154) | 0.97 (0.52 to 1.47) | -5% (-47–50%) | 3,620 (2,130 to 5,710) | 23.86 (13.67 to 36.56) | -13% (-51–37%) |
| Rwanda | Yes | 47 (33 to 67) | 0.80 (0.54 to 1.15) | -47% (-66% to -13%) | 1,800 (1,180 to 2,810) | 21.66 (14.90 to 31.20) | -54% (-72% to -14%) |
| Somalia | Yes | 317 (116 to 972) | 4.50 (1.55 to 14.13) | 3% (-34–68%) | 13,800 (5,100 to 42,600) | 124.26 (44.31 to 380.69) | -2% (-39–63%) |
| South Sudan | Yes | 102 (42 to 188) | 2.32 (0.91 to 4.28) | -23% (-49–12%) | 4,000 (1,700 to 7,270) | 62.48 (25.70 to 115.42) | -29% (-53–8%) |
| Uganda | Yes | 137 (94 to 196) | 0.87 (0.60 to 1.19) | -29% (-58–14%) | 5,790 (3,660 to 9,720) | 23.57 (16.06 to 33.72) | -34% (-60–10%) |
| United Republic of Tanzania | Yes | 211 (144 to 303) | 0.78 (0.52 to 1.09) | -27% (-52–9%) | 8,350 (5,190 to 15,100) | 20.94 (14.27 to 29.98) | -35% (-57–1%) |
| Zambia | Yes | 88 (58 to 128) | 1.06 (0.69 to 1.47) | -16% (-45–32%) | 3,960 (2,490 to 6,280) | 31.48 (20.63 to 45.61) | -28% (-57–22%) |
| **Southern Sub-Saharan Africa** | | **71 (56 to 90)** | **0.12 (0.09 to 0.15)** | **-33% (-46% to -16%)** | **3,050 (2,320 to 4,110)** | **4.22 (3.27 to 5.58)** | **-37% (-51% to -19%)** |

| | | Deaths | | | YLLs | | |
|---|---|---|---|---|---|---|---|
| Botswana | Yes | 6.5 (3.1 to 12) | 0.39 (0.19 to 0.72) | -36% (-65–4%) | 298 (139 to 567) | 14.42 (6.86 to 26.85) | -36% (-65–1%) |
| Eswatini | Yes | 2.3 (1.2 to 3.8) | 0.31 (0.17 to 0.51) | -36% (-63–3%) | 111 (59 to 189) | 11.31 (6.04 to 19.10) | -39% (-64–1%) |
| Lesotho | Yes | <1 (<1 to 1.8) | 0.07 (0.04 to 0.12) | -26% (-63–28%) | 44 (25 to 76) | 2.47 (1.39 to 4.36) | -29% (-65–22%) |
| Namibia | Yes | 4.5 (2.7 to 6.7) | 0.27 (0.16 to 0.40) | -46% (-68% to -9%) | 194 (112 to 299) | 9.26 (5.45 to 14.04) | -48% (-71% to -7%) |
| South Africa | Yes | 20 (17 to 26) | 0.04 (0.04 to 0.06) | -48% (-59% to -32%) | 795 (658 to 1,010) | 1.52 (1.27 to 1.94) | -59% (-69% to -43%) |
| Zimbabwe | Yes | 36 (26 to 48) | 0.47 (0.33 to 0.62) | -5% (-34–30%) | 1,600 (1,080 to 2,330) | 13.35 (9.35 to 17.90) | -7% (-35–28%) |
| **Western Sub-Saharan Africa** | | **3,820 (2,680 to 6,000)** | **1.42 (1.03 to 2.06)** | **-28% (-46–2%)** | **195,000 (131,000 to 334,000)** | **49.06 (34.39 to 76.69)** | **-33% (-51–1%)** |
| Benin | Yes | 108 (57 to 166) | 1.54 (0.84 to 2.18) | -12% (-44–25%) | 5,480 (2,850 to 9,310) | 51.39 (27.78 to 79.18) | -20% (-51–25%) |
| Burkina Faso | Yes | 279 (185 to 434) | 2.04 (1.45 to 2.75) | -20% (-44–19%) | 15,000 (8,830 to 27,300) | 72.50 (49.06 to 108.86) | -20% (-47–30%) |
| Cabo Verde | No | – | – | – | – | – | – |
| Cameroon | Yes | 264 (141 to 374) | 1.68 (0.89 to 2.32) | -9% (-46–46%) | 12,300 (6,640 to 19,000) | 54.42 (29.16 to 77.25) | -12% (-50–45%) |
| Chad | Yes | 236 (113 to 426) | 2.57 (1.25 to 4.50) | 23% (-18–70%) | 12,400 (5,730 to 22,900) | 88.67 (43.98 to 156.98) | 16% (-27–64%) |
| Côte d'Ivoire | Yes | 256 (169 to 376) | 1.78 (1.25 to 2.42) | -30% (-52–0%) | 12,100 (7,380 to 19,400) | 57.96 (38.31 to 85.09) | -32% (-57–3%) |
| Gambia | Yes | 9.4 (6.1 to 15) | 0.84 (0.56 to 1.30) | -38% (-64–2%) | 371 (218 to 695) | 24.26 (15.51 to 39.03) | -43% (-69% to -1%) |
| Ghana | Yes | 245 (180 to 335) | 1.34 (0.99 to 1.82) | -20% (-48–33%) | 10,100 (7,120 to 14,700) | 41.71 (30.26 to 57.77) | -26% (-52–25%) |

| | | Deaths | | | YLLs | | |
|---|---|---|---|---|---|---|---|
| Guinea | Yes | 191 (99 to 308) | 2.35 (1.22 to 3.65) | 12% (-32–66%) | 9,820 (4,990 to 16,900) | 84.47 (43.83 to 134.77) | 0% (-43–62%) |
| Guinea-Bissau | Yes | 16 (9.8 to 27) | 1.77 (1.07 to 2.75) | -28% (-55–10%) | 737 (419 to 1,290) | 55.70 (33.14 to 90.83) | -36% (-63–4%) |
| Liberia | Yes | 42 (22 to 80) | 1.60 (0.85 to 2.92) | -23% (-54–32%) | 1,880 (937 to 3,770) | 50.70 (26.19 to 96.17) | -39% (-67–22%) |
| Mali | Yes | 234 (131 to 481) | 1.68 (0.99 to 3.25) | -37% (-59–0%) | 12,900 (6,770 to 29,000) | 61.92 (35.26 to 124.08) | -41% (-66–6%) |
| Mauritania | Yes | 13 (6.9 to 25) | 0.57 (0.30 to 1.03) | -48% (-70% to -16%) | 477 (233 to 1,010) | 16.20 (8.33 to 31.38) | -54% (-76% to -22%) |
| Niger | Yes | 228 (123 to 473) | 1.66 (0.92 to 3.33) | -27% (-52–10%) | 13,100 (6,540 to 28,900) | 59.76 (32.73 to 121.22) | -35% (-64–10%) |
| Nigeria | Yes | 1,460 (977 to 2,640) | 1.13 (0.79 to 1.89) | -40% (-58% to -7%) | 78,000 (49,300 to 152,000) | 39.94 (26.62 to 71.98) | -44% (-62% to -9%) |
| Sao Tome and Principe | Yes | <1 (<1 to <1) | 0.04 (0.02 to 0.06) | -37% (-60–2%) | 2.1 (1.2 to 4.6) | 1.23 (0.74 to 2.38) | -52% (-72% to -18%) |
| Senegal | Yes | 77 (51 to 115) | 0.90 (0.60 to 1.3) | -39% (-62% to -6%) | 3,060 (1,860 to 5,090) | 26.90 (17.51 to 40.67) | -46% (-69% to -10%) |
| Sierra Leone | Yes | 90 (47 to 143) | 1.76 (0.93 to 2.70) | -5% (-43–49%) | 4,610 (2,390 to 7,670) | 62.63 (32.79 to 99.58) | -14% (-52–54%) |
| Togo | Yes | 70 (37 to 103) | 1.64 (0.87 to 2.34) | -6% (-44–43%) | 3,050 (1,670 to 4,860) | 51.12 (27.27 to 76.40) | -17% (-51–34%) |

Burden by region and SDI

Mortality due to venomous snakebite showed substantial regional variation (Figure 3). South Asia had the greatest burden, with 54,600 deaths (95% UI 31,800–68,300) and 2.54 million YLLs (1.48 million–3.21 million), accounting for 86% (76–92) of global deaths and 86% (78–91) of global YLLs. The age-standardized death and YLL rates were equal to 3.4 deaths (2.0–4.2) per 100,000 and 144 YLLs (83–182) per 100,000, respectively. Western, central, and eastern sub-Saharan Africa had the next-highest venomous snakebite mortality, with 1.4 deaths (1.0–2.1), 1.3 deaths (0.8–1.8), and 1.2 deaths (0.8–1.6) per 100,000, respectively (Table 1). The regions with the lowest age-standardized rates in 2019 were central Europe, high-income North America, high-income Asia Pacific, and western Europe. At the regional level, there was a log-linear relationship between the SDI of a region and the region's age-standardized venomous snakebite mortality rate in 2019 (Figure 4).

India had the greatest absolute number of venomous snakebite deaths in 2019 at 51,100 deaths (95% UI 29,600–64,100), followed by Pakistan and Nigeria (2070 deaths [1470–2950] and 1460 deaths [977–2640], respectively). In India in 1990, the age-standardized rate of venomous snakebite death per 100,000 was 7.3 (4.1–8.8) and decreased to 4.0 (2.3–5.0) in 2019, which represents the greatest absolute decrease over that timespan globally. Within India, Chhattisgarh, Uttar Pradesh, and Rajasthan had the greatest age-standardized death rates, at 6.5 deaths (3.5–8.4), 6.0 deaths (2.6–8.0), and 5.8 deaths (3.5–7.4) per 100,000, respectively. Uttar Pradesh had the greatest absolute number of deaths of any state in India in 2019, with 12,000 deaths (5230–16,100). See Appendix Table 5 for state-level results for all of India.

Forecasted mortality to 2050

By 2050, the rate of venomous snakebite mortality globally is expected to decrease to an age-standardized rate of 0.67 deaths (95% UI 0.39–1.1) per 100,000 (Figure 5). This is equivalent to 68,800 absolute deaths (39,100–126,000), which is greater than the number of deaths that occurred in 2019, due to forecasted population increases. By 2030, we predict the global age-standardized rate will non-significantly decrease by 8.6% (−9.6 to 20.1), if the current time trend continues. See Appendix Table 6 for each region's forecasting results, by decade from 2020 to 2050.

# Discussion

Venomous snakebite caused 63,400 deaths (95% UI 38,900–78,600) and 2.94 million YLLs (1.79 million–3.74 million) in 2019, which makes it the deadliest NTD according to GBD 2019.[11] Over time, the global age-standardized rate of death has decreased by 36% (2–49), which shows progress; however, this annual rate of change would be insufficient to accomplish WHO's 2019 goal of halving the burden by 2030.[4]

The greatest venomous snakebite mortality occurred in south Asia, and specifically India, where we estimated over 50,000 deaths occurred in 2019. These estimates are consistent with previous research conducted with verbal autopsy mortality surveys, which were the source of data in India in our process as well.[9,10,17] The high mortality in India is an example of ecological factors, socioeconomic factors, and health system shortcomings intersecting to create a vulnerable population to preventable snakebite death. After venomous snakebite occurs, the probability of death increases if antivenom is not administered within six hours.[18] However, in south Asia, many seek out traditional healers or attend clinics with insufficient education about how to treat venomous snakebites or lack the antivenom to administer life-saving treatment.[18–21] Victims who do reach a hospital often have insufficient access to dialysis, ventilators, and blood transfusions, which are essential to deal with the complications of envenoming.[20,22] Interventions to secure more rapid antivenom delivery need to be coupled with preventive strategies like increased education and health system strengthening in rural areas.

Sub-Saharan Africa had the second greatest mortality with 6790 deaths (95% UI 5040–10,100) and 314,000 YLLs (219,000–521,000), equivalent to age-standardized rates of 1.2 deaths (0.9–1.6) per 100,000 and 36.9 YLLs (27.3–54.6) per 100,000. In the WHO's 2019 updated Strategy for Prevention and Control of Snakebite

Envenoming in sub-Saharan Africa, updated and precise epidemiological data were outlined as a need moving forward to better guide appropriate and efficient implementation of antivenom interventions.[23] However, there are no robust verbal autopsy or vital registration systems in the area; precise measurement of deaths is difficult and statistical modeling is required. Recently, political determination to curb venomous snakebites in sub-Saharan Africa has improved, and we hope these estimates prompt further support for antivenom distribution and detailed epidemiological studies on the extent of venomous snakebite in sub-Saharan Africa.

Our ensemble modelling framework allowed us to test multiple covariates for their association with venomous snakebite mortality providing important insights on the disease epidemiology. Environmental indicators such as living at a lower elevation and latitude and socioeconomic indicators like education had strong negative associations with venomous snakebite mortality (Appendix Figure 4). We found education had a more negative association for males, while urbanicity was more strongly negative for females. These findings aligned with previous research that reported higher venomous snakebite mortality in females than males in rural areas.[10] We show that at a population level, interventions for rural areas focused on antivenom delivery should be supplemented with education for agricultural workers to increase awareness of high-risk behaviors and mitigation strategies. With better epidemiological data, more data-driven implementation of proven interventions can be achieved, like the use of education, rapid emergency transport for agricultural workers, as well as rigorous evaluation of innovative interventions like antivenom delivery via drones to at-risk rural locations.[24–27]

When paired with the recent analysis by Longbottom *et al.* that mapped the vulnerability to snakebite envenoming, our high-level estimates present a complementary assessment of the drivers behind venomous snakebite mortality, and especially highlight gaps in antivenom access in many areas of the world.[28] In some places, their results intersected with locations we estimated to have high mortality rates, such as central and eastern sub-Saharan Africa, which Longbottom *et al.* estimated have significant vulnerability due to poor health system infrastructure and the presence of snakes. Conversely, we found that high rates of mortality also occur in areas that Longbottom *et al.* did not estimate to have high vulnerability, such as India. This is likely due to the existence of antivenom for the "big four" snakes (*Bungarus caeruleus, Daboia russelii, Echis carinatus, Naja naja*) that cause the majority of envenomations in the country, while the vulnerability estimates were focused on exposure to snakes that do not have antivenom treatments.[18,28] Our mortality estimates demonstrate that venomous snakebite death depends on more than just the existence of antivenom, but also its dissemination to rural areas and the health system capacity of the area to provide supportive care to victims with secondary complications such as neurotoxic respiratory failure or acute kidney injury requiring dialysis.[29] Future studies should improve the resolution of mortality at a more detailed spatial level, and combine metrics of human-snake interactions, health system capabilities, and disease burden. A more granular spatial level will also reveal disparities not captured in this analysis. Greater temporal resolution incorporating the seasonality of venomous snakebites, especially in south Asia where the incidence of bites increases during the rainy season, would also be useful for decision makers.

### Limitations and strengths

In this analysis, we incorporated an extensive amount of ICD-coded VR and VA data that has previously not been utilized in global snakebite estimates. However, even in this dataset there was sparsity across some locations, especially in sub-Saharan Africa and Southeast Asia where there are few robust in-country data reporting systems. Despite sparse data, our estimate of 6790 deaths (95% UI 5040–10,100) in sub-Saharan Africa aligns closely with the meta-analysis by Chippaux and colleagues, which estimated there were 7331 (5149—9568) annual deaths.[7] Both studies have the same problems of data scarcity, are likely underestimates of the true number of deaths, and emphasize the urgent need for better epidemiological assessments to provide a more accurate assessment of the true disease burden due to venomous snakebite in sub-Saharan Africa, South Asia, and Southeast Asia.

Verbal autopsy and vital registration are also both imperfect methods for counting venomous snakebite deaths and represent another limitation in our study. We could still be underestimating the true magnitude of death if the distinctive signs of snakebite, or the snake itself, were not seen when the bite occurred. For example, in Cambodia, only a single verbal autopsy study including venomous animal mortality has been conducted to our knowledge in the country,[30] which did not find a single death due to venomous snakebite, despite the presence of multiple venomous snakes in the country.[14] This highlights the need for improved focused venomous snakebite surveillance in areas where venomous snakes are known to be endemic.

Alternatively, official death statistics have been shown to miss many venomous snakebite deaths or miscode them as another cause. Studies comparing verbal autopsy community-based studies and official records frequently find that official records undercount the number of deaths that actually occurred.[9,10,21] Acknowledging these limitations in vital registration data, we attempted to use post-processing steps like redistribution of ill-defined causes of death to attempt to account for underreporting.[31] However, given that many venomous snakebite deaths occur in rural settings in countries without strong cause of death surveillance or vital registration systems, underreporting likely still occurred and our estimates are potentially underestimates, given the limitations of the epidemiological data.

To improve future studies, questions related to venomous snakebites should be incorporated into regular health surveys that are already being conducted across sub-Saharan Africa and south Asia. Injury surveillance, such as the use of District Health Information System 2, has also shown promise and could be adapted to snakebites to create real-time epidemiological information.[32] Increased collaboration between researchers and local health institutions should be prioritized to bolster the availability of data, demonstrate the unmet need for antivenom, and rigorously monitor and evaluate interventions.

Our analysis also relied on the WHO venomous snake distribution map to decide which locations could reliably be identified as having venomous snakes of medical importance and which did not. It was important for our results to be ecologically feasible, and this database represented the most complete list of venomous snakes capable of causing mortality that we could find. However, while it is updated iteratively, it is not complete and only contains approximately 200 venomous snakes deemed medically important, out of 600 venomous snakes. While these other 400 snakes may not cause fatalities regularly, they could cause fatal envenomation in rare cases. If a country only contained one of these 400 venomous snakes that was capable of a rare fatal envenomation and not one of the 200 medically important snakes, then we would be erroneously zeroing out that location. For example, there is the Solomons Coral Snake (*Salmonelaps par)* in Solomon Islands, that has no recorded fatal envenomations but there are case reports of near lethal bites.[33] Conversely, there were countries where we had official health statistics data that recorded an ICD-coded death due to venomous snakebite in Chile and New Zealand. Based on review of the WHO venomous snake distribution database and venomous snake habitats, we agreed with the WHO venomous snake distribution database that there were no endemic venomous snakes despite these recorded deaths.

# Conclusion

In conclusion, we provide the most comprehensive and data-driven estimates of the magnitude of venomous snakebite mortality to date. We find that deaths are concentrated in south Asia; however, sub-Saharan Africa also has a high disease burden due to venomous snakebites. Significant investments in data collection, research, and public health intervention are required to better quantify the magnitude of venomous snakebite in sub-Saharan Africa. Securing timely antivenom access across rural areas of the world would save thousands of lives, and greater investment into devising and scaling these up should be prioritized to meet WHO's venomous snakebite and neglected tropical disease goals.

# Methods

Summary

We started with reviewing GBD 2019 mortality estimates for venomous animal contact. The GBD study and its methodological framework to estimate mortality due to injuries have been described in detail elsewhere.[11,12]

In brief, we used a subset of the data for venomous animal contact to identify snakebite-specific mortality, as well as other animal-specific mortality, and evaluated these data using models that captured spatiotemporal patterns to estimate mortality for four different animals (snakes, bees, scorpions, spiders) and for a fifth residual category (other venomous animal contact). We adjusted each animal-specific mortality estimate so that their sum equaled the GBD 2019 overall venomous animal contact mortality estimates, thus preserving internal consistency. To account for uncertainty in the primary data, data processing, measurement error, and choice of model, every model in the process was run 1000 times to produce final estimates with 95% uncertainty intervals, which comprise the 2.5th and 97.5th percentiles of the 1000 draws.

GBD 2019 venomous animal contact estimation

We used published GBD 2019 estimates for overall venomous animal contact mortality as a platform for our analysis. A summary of the GBD 2019 estimation approach for mortality from venomous animal contact follows.

The case definition for a venomous animal contact death in GBD 2019 was "death resulting from unintentionally being bitten by, stung by, or exposed to a non-human venomous animal". We identified deaths in vital registration (VR) and verbal autopsy (VA) cause of death data using ICD-9 codes E905-E905.99 and ICD-10 codes X20-X29.9. Once data from all available sources were identified, data underwent the processing that occurs for all cause-of-death data in GBD, which includes noise reduction to reduce stochastic variation and redistribution of unspecified or incorrectly coded causes of death, which is important for venomous snakebites which can manifest in multiple injuries after systemic envenomation and be mis-attributed to a different cause of death. These data preparation steps are described in detail elsewhere.[11] See Appendix Figure 1 for a map of data used in the GBD 2019 venomous animal contact model.

Next, mortality due to venomous snakebites was modelled using GBD cause of death ensemble modeling (CODEm). CODEm is described in more detail elsewhere, and essentially explores a large variety of possible submodels to estimate trends in causes of death using an algorithm to select varying combinations of covariates that are run through several modelling classes.[13] Covariates are also included to guide predictions where data are sparse or absent. Covariates for venomous animal contact are listed in Appendix Table 1. The predictive validity of each one of the submodels is tested using test-train holdouts, whereby a specific model is trained on 70% of the data and tested on the withheld 30% of data to determine out-of-sample predictive validity. Once the submodels are conducted and predictive validity is measured, then an ensemble model is developed out of the submodels. The best-performing models are chosen based on out-of-sample predictive validity. Years of life lost (YLLs) are calculated by multiplying cause-specific mortality rates by the residual life expectancy at the age of death (Appendix Table 2).

Study design and data sources

After GBD 2019 venomous animal contact mortality was estimated, we undertook the following steps to estimate snakebite-specific mortality.

We first reviewed all cause of death data that could be mapped directly to snakebites or other venomous animals. The ICD codes used for each animal are listed in Appendix Table 3 along with the volume and type of data used in snakebite modelling. The snakebite-specific model had 10,636 location-years of data. See Appendix Figure 2 and Appendix Figure 3 for maps of the volume of data used in the venomous snakebite model and the type of data in each location.

After obtaining all possible data, we applied the same cause of death noise reduction processing described above to the raw animal-specific data.[11] We redistributed deaths coded to ICD codes E905, E905.9, and X29 – which code for deaths due to unspecified venomous animals – by aggregating all the properly coded deaths by location, age, sex, and animal, and applying the proportion of correctly coded deaths due to snakebites to the number of deaths coded for unspecified venomous animal. Redistribution was based on location, age, and sex patterns from correctly coded venomous animal deaths. See Appendix p 3 for further detail.

# Statistical analysis

Following noise reduction and redistribution of ill-defined causes of death, we developed statistical models based on the spatiotemporal Gaussian process regression (ST-GPR) modelling framework used in GBD.[11] ST-GPR starts by fitting a mixed-effects linear prior and then fitting a second model based on the weighted residuals between the input data and the linear prior. We set the second-stage model weights to allow high smoothing over time due to a prior expectation that the burden of snakebite does not change substantially year after year, low smoothing over space because of a prior that the burden of countries within a region can vary substantially, and a medium weight over age to allow age smoothing while not overfitting. The exact details regarding model weight calculations are in Appendix pp 7. Every combination of covariates (Appendix Table 1) was tested in a mixed-effects model with snakebite deaths per 100,000 people as the outcome variable. An ensemble of the best-performing models was developed which acted as the first-stage linear prior in the ST-GPR model, weighted by out-of-sample RMSE. The model weights are defined by spatial distance across world regions and temporal distance.

We ran ST-GPR models for snakes, bees, scorpions, spiders, and a fifth "other venom" category to estimate the rate of death from all five animals for 204 countries, 23 age groups, males and females, for every year between 1980 and 2019 inclusive. To ensure the ecological feasibility of our results, we zeroed out all locations that do not have endemic venomous snakes of medical importance, according to the WHO database on global venomous snake distribution.[14] Countries with zero snake deaths are given in Appendix Table 4. The WHO venomous snake distribution database maps out the habitats of over 200 medically important venomous snakes, out of the 600 venomous snakes and 3000 overall species of snakes. The distribution map is based on published reference texts, scientific journals, museum collection databases, and consultation with zoologists and snakebite experts from around the world.[14] For each location, age, sex, and year demographic, we aggregated together the results from all five different animals to derive the proportion of overall venomous animal deaths due to snakebites. This proportion was applied to the GBD 2019 venomous animal contact results from 1990 to 2019 to calculate the snakebite cause-specific mortality rate (CSMR). Figure 1a displays the GBD 2019 all-ages rate of death from venomous animal contact, while Figure 1b displays the proportion of those deaths due to just snakebite.

Extrapolation, age-standardization, and forecasting for 2020 to 2050 estimates

Estimates for GBD 2019 span from 1990 to 2019. To estimate the number of deaths due to venomous snakebites from 2020 to 2050 in ten-year intervals, we input the venomous snakebite results into a regression with year and age as predictors. We conducted each regression by sex and region separately and added a cubic spline on age. Each sex- and region-specific regression was run 1000 times, and the resulting coefficients were used to predict rates in the years 2020, 2030, 2040, and 2050. Predicted rates were multiplied by forecasted population and standardized using the GBD 2019 standard population.[15] No steps were made to align GBD 2019 CSMR estimates with the predicted forecast from 2020, and predictions were made on the average annualised rate of change and the age-sex demographic composition of each region.

Socio-demographic Index

Socio-demographic Index (SDI) is a summary measure of development, taking into account a country's total fertility rate for women younger than 25 years, educational attainment, and lag-distributed income per capita. Methods to produce SDI are discussed elsewhere.[11]

GATHER compliance

This study complies with the Guidelines for Accurate and Transparent Health Estimates Reporting (GATHER) recommendations (Appendix pp 13-14).[16]

# Data Availability

A full list of sources used in the venomous animal contact mortality estimation process in the Global Burden of Disease study is available through the Global Health Data Exchange at http://ghdx.healthdata.org/.

## Declarations

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# Ethics Declarations

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# Figures

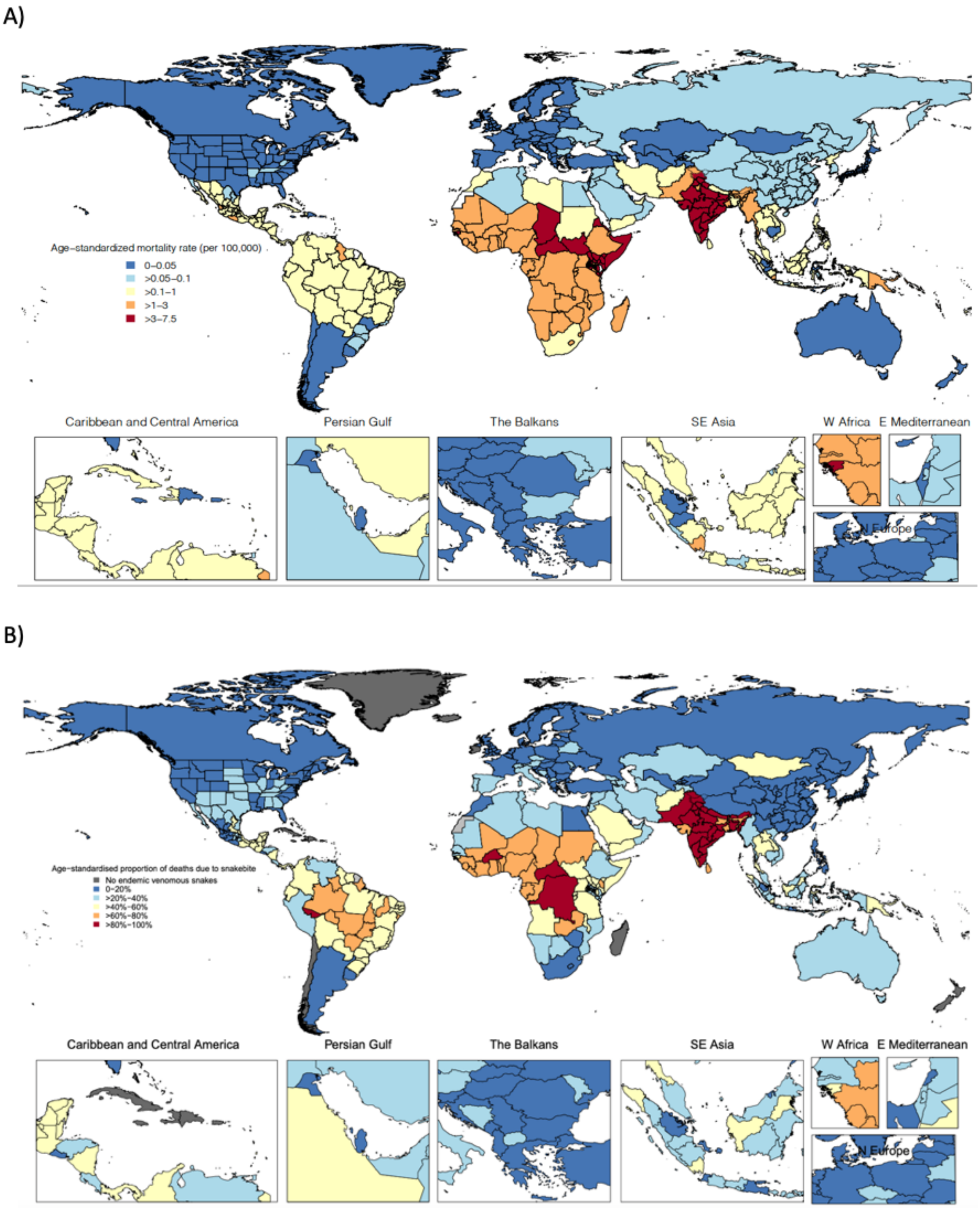



**Figure 1**

A) GBD 2019 estimates of the rate of death from venomous animal contact for both sexes combined, all ages, in 2019. B) Estimate of the proportion of all venomous animal contact deaths due to only snakebites. GBD 2019 did not publish state-level estimates for China, and each state is colored the estimate of the rate of China's national estimate. Endemic habitat of venomous snakes of medical importance was looked up from the WHO venomous snake distribution maps: https://apps.who.int/bloodproducts/snakeantivenoms/database/default.htm.

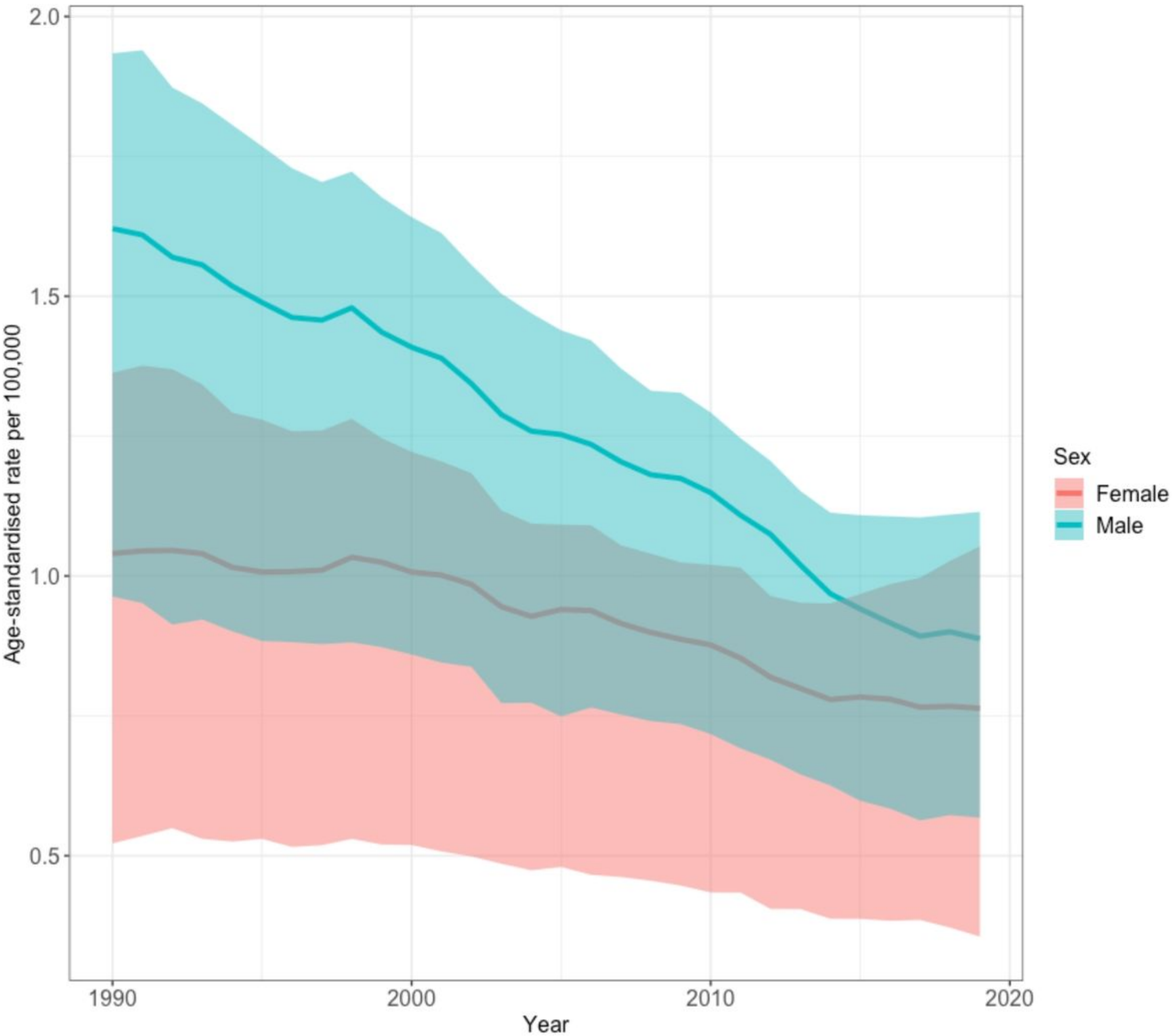
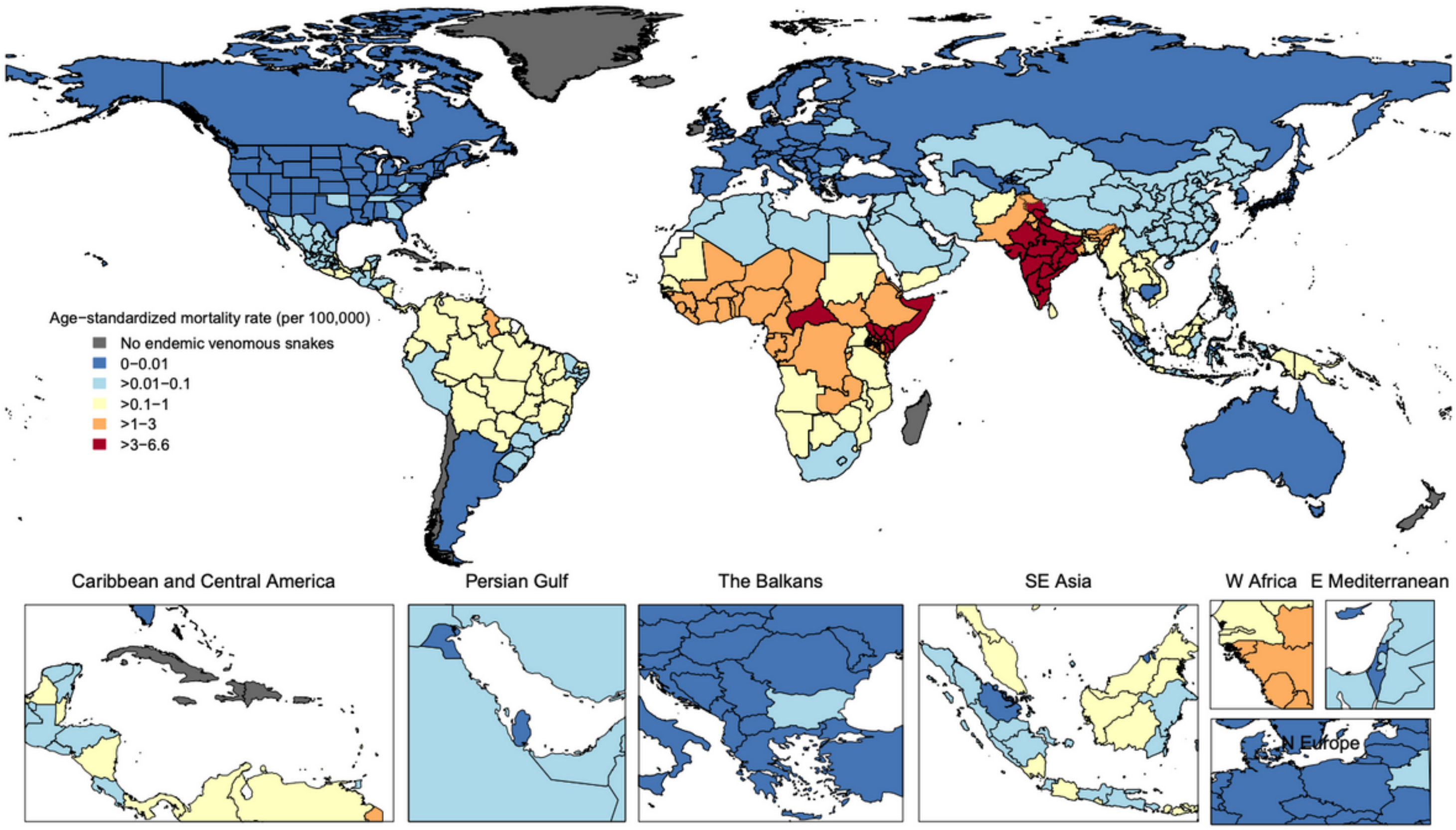


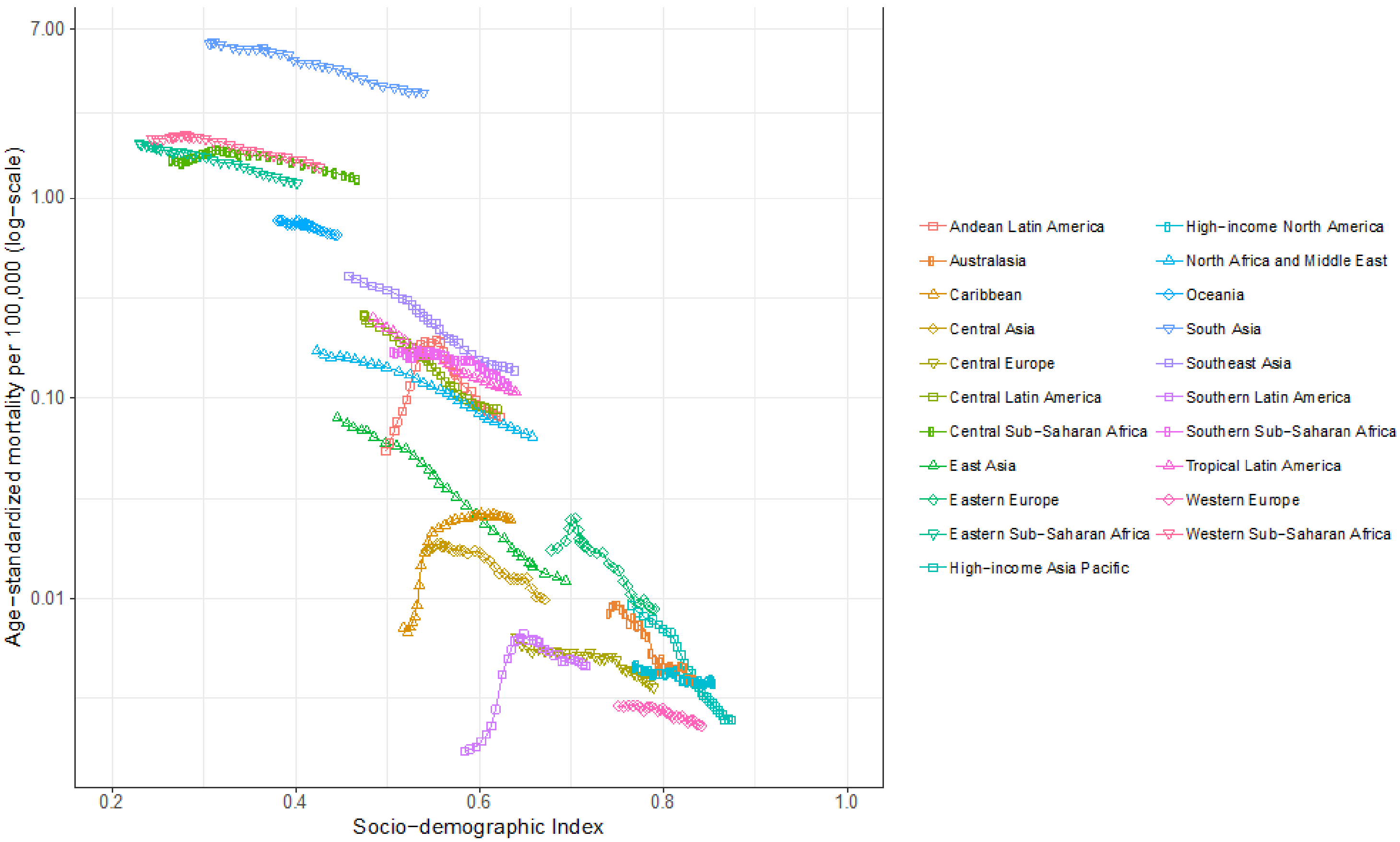

**Figure 2**

Global age-standardized venomous snakebite mortality over time by sex.




## Figure 3

Age-standardized venomous snakebite mortality rates in 2019, both sexes combined. GBD 2019 did not publish state-level estimates for China, and each state is colored the estimate of the rate of China's national estimate. Endemic habitat of venomous snakes of medical importance was looked up from the WHO venomous snake distribution maps: https://apps.who.int/bloodproducts/snakeantivenoms/database/default.htm.




## Figure 4

Age-standardized venomous snakebite mortality rate per 100,000 by region and Socio-demographic Index. Each point represents the age-standardized mortality in a given year from 1990 to 2019 of the region. Y-axis is in log scale.

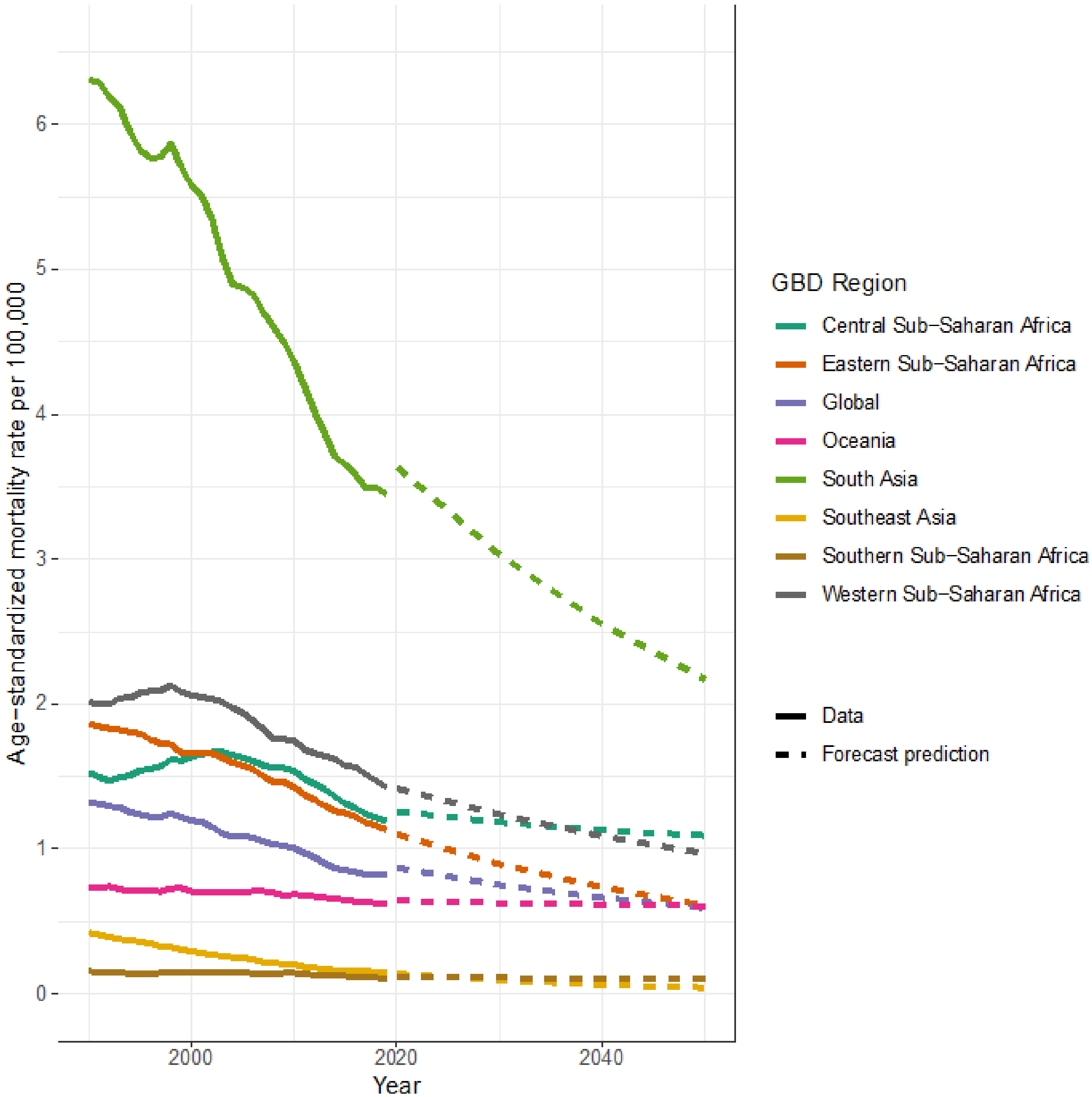



**Figure 5**

Age-standardized venomous snakebite mortality rate per 100,000 by region and year, forecasted to 2050. The plot shows the top seven regions in terms of age-standardized rates, all of which had age-standardized mortality rates greater than 0.1 per 100,000 in 2019. Lines in bold are our venomous snakebite CSMR estimates, while dotted lines are the predictions from the forecast regression. No steps were made to align GBD 2019 CSMR estimates with the predicted forecast from 2020, and predictions are made based on the average annualized rate of change from 1990 to 2019 and the age-sex demographic composition of each region.

# Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Snakebiteappendix.pdf