




OPEN

# Anemia prevalence in women of reproductive age in low- and middle-income countries between 2000 and 2018

Damaris Kinyoki<sup>1,2</sup>, Aaron E. Osgood-Zimmerman<sup>1</sup>, Natalia V. Bhattacharjee<sup>1</sup>, Local Burden of Disease Anaemia Collaborators\*, Nicholas J. Kassebaum<sup>1,2,3,4</sup> and Simon I. Hay<sup>1,2</sup> 

**Anemia is a globally widespread condition in women and is associated with reduced economic productivity and increased mortality worldwide. Here we map annual 2000–2018 geospatial estimates of anemia prevalence in women of reproductive age (15–49 years) across 82 low- and middle-income countries (LMICs), stratify anemia by severity and aggregate results to policy-relevant administrative and national levels. Additionally, we provide subnational disparity analyses to provide a comprehensive overview of anemia prevalence inequalities within these countries and predict progress toward the World Health Organization’s Global Nutrition Target (WHO GNT) to reduce anemia by half by 2030. Our results demonstrate widespread moderate improvements in overall anemia prevalence but identify only three LMICs with a high probability of achieving the WHO GNT by 2030 at a national scale, and no LMIC is expected to achieve the target in all their subnational administrative units. Our maps show where large within-country disparities occur, as well as areas likely to fall short of the WHO GNT, offering precision public health tools so that adequate resource allocation and subsequent interventions can be targeted to the most vulnerable populations.**

Anemia occurs when the number of healthy red blood cells is insufficient to meet the body’s physiological needs for oxygen delivery to the brain, heart, muscles and other vital tissues. Hemoglobin is the primary oxygen-carrying molecule within red blood cells, so anemia is most typically measured in terms of hemoglobin content of the blood rather than red blood cell volume<sup>1,2</sup>. Anemia can reduce cognitive and physical capacities and is associated with reduced economic productivity<sup>3,4</sup> and increased morbidity and all-cause mortality<sup>5</sup>. Maternal iron deficiency can lead to adverse pregnancy and newborn outcomes, including stillbirth, low birth weight and infant mortality<sup>6</sup>, and anemia in pregnancy has been suggested as a potential marker of increased risk of major hemorrhage<sup>7</sup> and a risk factor for maternal death<sup>8</sup>.

Causes of anemia can be divided into three non-mutually exclusive pathways: blood loss, increased red blood cell destruction and inadequate red blood cell production. Blood loss can be acute due to events such as injuries, maternal hemorrhage or surgery, or it can be chronic, due to conditions such as gastrointestinal disorders, helminthic infections, bleeding disorders or abnormal uterine bleeding<sup>9,10</sup>. Increased red blood cell destruction happens either as a consequence of abnormal red blood cell structure, such as in thalassaemia or sickle cell disease, or because of external mechanical, immune or infectious factors<sup>11</sup>. Inadequate production of red blood cells can happen when the bone marrow itself is depressed, such as in HIV<sup>12</sup> or some malignancies; because there are hormonal imbalances, such as with chronic inflammation<sup>13</sup> or due to increased demand (such as during pregnancy), nutrient malabsorption or inadequate supply of red blood cell building blocks, such as protein, iron, vitamin A<sup>14</sup>, folate or vitamin B-12 (ref. <sup>15</sup>). Iron deficiency is often thought of as the most common cause of

anemia, which is true but also misleading, because absolute and/or functional iron deficiency can arise as a consequence of any of the three pathways and, therefore, as a consequence of multiple different causes. Women of reproductive age (WRA; ages 15–49 years) are at particularly increased risk of iron deficiency and, therefore, anemia, compared to men, due to physiological changes such as menstruation (blood loss pathway), pregnancy (inadequate production pathway due to increased demand) and bleeding in childbirth<sup>16,17</sup>. Additionally, unequal household food allocation can make WRA vulnerable to anemia as they might not have access to iron-rich foods<sup>17</sup>.

Anemia continues to affect millions of women worldwide and remains concentrated in LMICs as defined by the Global Burden of Disease (GBD) Socio-Demographic Index (SDI)<sup>18</sup>. In 2019, 30.1% of WRA were estimated to have anemia globally, with wide geographical variation<sup>18</sup>, and dietary iron deficiency was among the highest-ranking conditions in both prevalence and years lived with disability (YLDs) among WRA in LMICs<sup>19</sup>. The WHO has set a GNT to reduce anemia in WRA by 50% by 2025 (refs. <sup>2,20</sup>); this target and other related WHO GNTs have since been extended to 2030 (ref. <sup>21</sup>). In October 2019, the percentage of WRA with anemia was officially added as an indicator to track progress toward the Sustainable Development Goal (SDG) 2.2 to end all forms of malnutrition by 2030 (refs. <sup>22,23</sup>). Although the WHO provides national-level anemia estimates and tracking tools, available reports do not show the subnational heterogeneity needed to inform within-country planning, annual changes to track progress or anemia severity stratifications<sup>20,24</sup>. Maps of comparable estimates across space and time at policy-relevant administrative levels are vital to identify the most vulnerable populations, track progress toward international

<sup>1</sup>Institute for Health Metrics and Evaluation, University of Washington, Seattle, WA, USA. <sup>2</sup>Department of Health Metrics Sciences, School of Medicine, University of Washington, Seattle, WA, USA. <sup>3</sup>Department of Anesthesiology & Pain Medicine, University of Washington, Seattle, WA, USA. <sup>4</sup>Department of Global Health, University of Washington, Seattle, WA, USA. \*A list of authors and their affiliations appears at the end of the paper. ✉e-mail: [sihay@uw.edu](mailto:sihay@uw.edu)

anemia goals and provide decision-makers and policy-makers with tools to aid targeted interventions.

This study is part of a series using high-spatial-resolution estimates to map progress toward the WHO GNTs<sup>25–27</sup>. To perform this study, we compiled an extensive geo-positioned dataset from 218 surveys representing over 3 million women. Using Bayesian model-based geostatistics and the assumption that locations with similar socioeconomic and environmental patterns and proximity in time and space would have similar anemia levels, we produced estimates for all areas across 82 LMICs, even where data were sparse. The geospatial nature of our estimates also allows for the flexibility to aggregate to different (and sometimes changing) boundaries and catchment areas over the observation period.

Here we present annual geospatial estimates from 2000 to 2018 of prevalence and absolute counts of anemia of WRA (non-pregnant and pregnant combined), stratified by severity and aggregated to first-level (for example, provinces) and second-level (for example, districts) administrative units and national levels across 82 LMICs. Overall anemia was defined as  $<12 \text{ g dl}^{-1}$  for non-pregnant WRA and  $<11 \text{ g dl}^{-1}$  for pregnant WRA<sup>28</sup>. Anemia severity categories are defined by the WHO: mild anemia ( $11.0\text{--}11.9 \text{ g dl}^{-1}$  for non-pregnant WRA;  $10.0\text{--}10.9 \text{ g dl}^{-1}$  for pregnant WRA), moderate anemia ( $8.0\text{--}10.9 \text{ g dl}^{-1}$  for non-pregnant WRA;  $7.0\text{--}9.9 \text{ g dl}^{-1}$  for pregnant WRA) and severe anemia ( $<8.0 \text{ g dl}^{-1}$  for non-pregnant WRA;  $<7.0 \text{ g dl}^{-1}$  for pregnant WRA). We also discuss our results in light of public health problem thresholds: no public health problem ( $<5\%$  overall anemia prevalence), low public health problem ( $5\text{--}19.9\%$  overall anemia prevalence), medium public health problem ( $20\text{--}39.9\%$  overall anemia prevalence) and high public health problem ( $\geq 40\%$  overall anemia prevalence)<sup>28</sup>. We show annualized rates of change (AROCs) between 2000 and 2018 and estimate the probability of achieving the WHO GNT by 2025 and 2030 based on recent trends. Additionally, we provide subnational disparity analyses. These estimates can aid in focusing attention on exemplars of progress, highlighting subnational inequalities and identifying locations requiring further investments. The full suite of outputs from the analysis are publicly available on the Global Health Data Exchange (<http://ghdx.healthdata.org/record/ihme-data/global-anemia-prevalence-geospatial-estimates-2000-2019>) and via our interactive data visualization tool (<https://vizhub.healthdata.org/lbd/aneamia>).

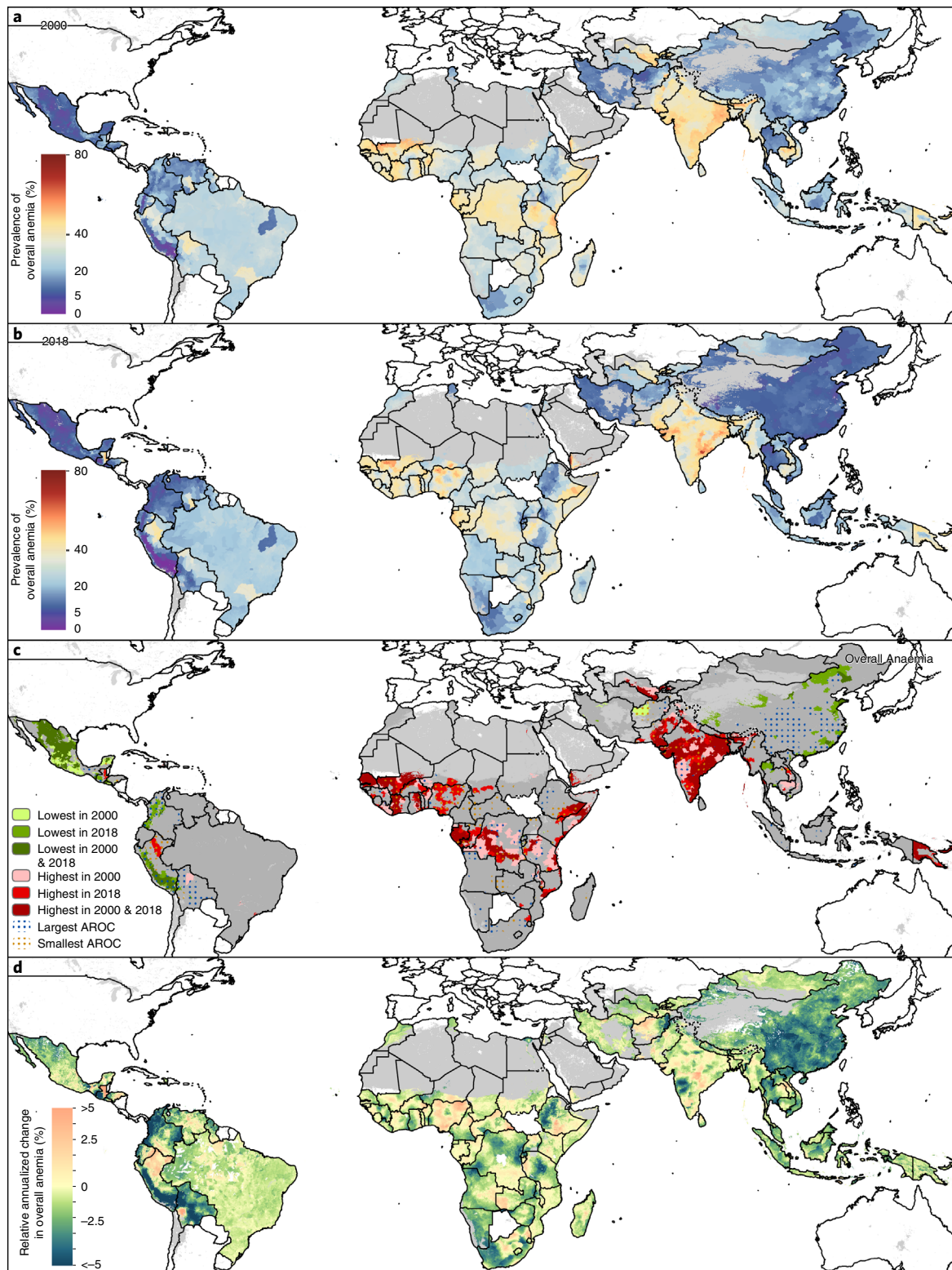
## Results

**Prevalence and trends of overall anemia.** The prevalence of overall anemia among WRA varied broadly across LMICs (Fig. 1a,b). In 2018, anemia prevalence was highest in West African, Middle Eastern and South Asian countries, including Gambia (50.3% (95% uncertainty interval: 43.3–57.5)), Senegal (47.3% (43.4–50.1)), Mali (47.6% (45.8–49.4)), Yemen (57.4% (50.9–63.8)) and India (49.9% (47.2–52.4)). The lowest national-level anemia prevalence in 2018 was found in Central America and the Caribbean, Andean South America and East Asia, including El Salvador (8.2% (3.6–16.1)), Colombia (9.2% (4.5–17.0)), Mexico (10.4% (7.3–15.3)) and China (11.1% (9.1–13.1)).

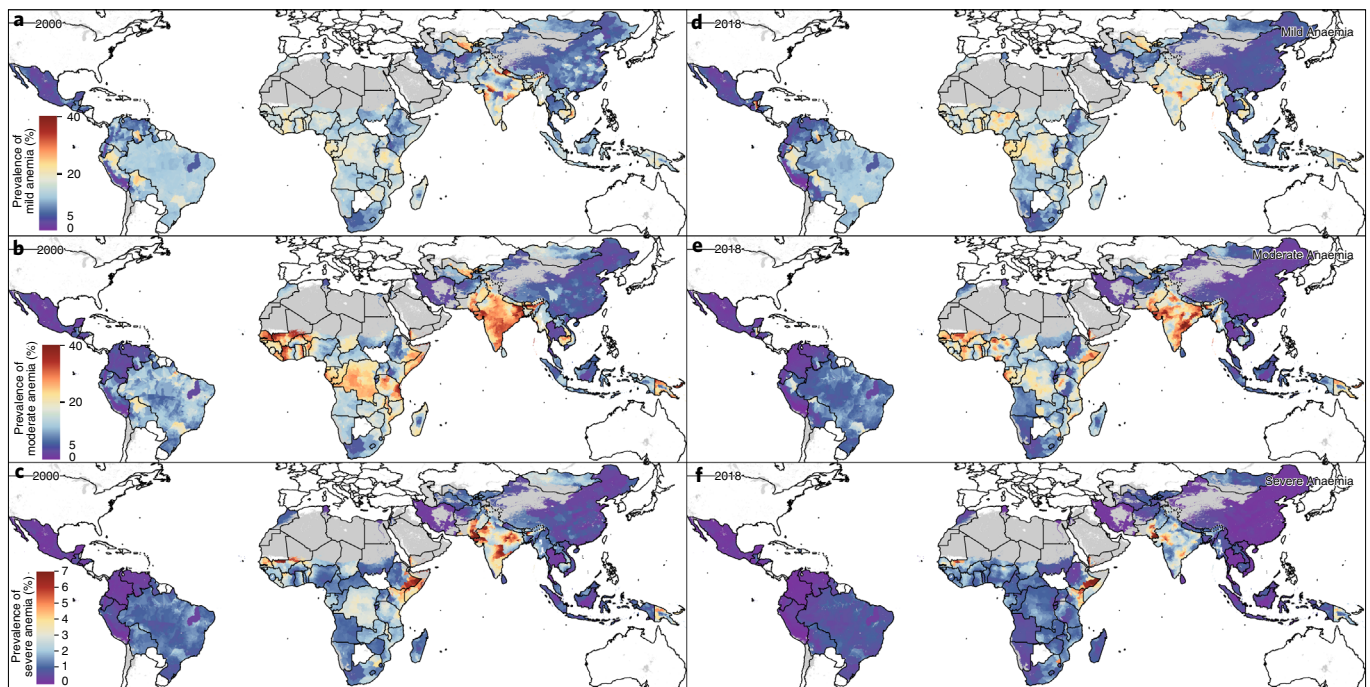
Gradual declines on a global scale indicate that little progress was seen in reducing anemia on a more local scale. Across the 82 LMICs, overall anemia among WRA decreased from 35.6% (25.7–46.9) in 2000 to 31.6% (25.2–39.1) in 2018. High levels of anemia remained widespread in 2018, with just over half (56.1%; 46 of 82) of LMICs with 20–39.9% prevalence of mean national-level overall anemia in 2018. On a subnational scale, 80 (97.6%) LMICs had at least one second administrative-level unit (hereafter ‘district’), and 38 (46.3%) LMICs had a majority of districts with 20–39.9% mean overall anemia prevalence. Over a quarter of LMICs (25.6%; 21 LMICs) had  $>40\%$  mean national-level anemia in 2018, whereas 76 (92.7%) had at least one district, and 22 (26.8%) LMICs had most of their districts, with  $>40\%$  mean overall anemia prevalence.

Anemia was at unacceptable levels ( $>5\%$  prevalence)<sup>28</sup> in 99.7% (21,868 of 21,917) of districts across LMICs in 2000 and 98.9% (21,686 of 21,917) in 2018. (Fig. 1a,b). In 2000, 30.7% (6,725 of 21,917), 48.9% (10,726 of 21,917) and 20.1% (4,417 of 21,917) of subnational districts had low (5–19.9%), medium (20–39.9%) and high ( $\geq 40\%$ ) public health threat levels of anemia among WRA<sup>28</sup>, respectively (Extended Data Table 1). Global shifts led to 37.7% (8,273 of 21,917), 43.5% (9,523 of 21,917) and 17.7% (3,881 of 21,917) of districts having low, medium and high public health problem levels in anemia prevalence among WRA, respectively, in 2018. Only two countries (Peru and Ecuador) had districts that maintained levels below 5% prevalence of overall anemia in both 2000 and 2018. In Peru, 36 of 195 (19.5%) districts had overall anemia prevalence levels  $<5\%$  in both 2000 and 2018, such as in San Román (Puno) in the south (2.3% (1.1–4.3) in 2000; 0.4% (0.2–0.7) in 2018); in Ecuador, only one of 223 (0.4%) districts mean estimates achieved  $<5\%$  prevalence in both years: the centrally located Cevallos (Tungurahua) (4.4% (1.0–12.5) in 2000; 4.6% (1.2–11.4) in 2018). Although Mexico had 16 districts and Iran had two districts below public health problem levels ( $<5\%$ ) in 2000, these districts exceeded 5% overall anemia prevalence in 2018. In 2018, only nine LMICs had at least one district with no public health problem in anemia ( $<5\%$ ), including Bolivia (two of 114 districts), Colombia (13 of 1,065 districts), Ecuador (one of 223 districts), El Salvador (six of 266 districts), Guatemala (87 of 354 districts), Mexico (25 of 2,454 districts), Thailand (one of 928 districts) and Uganda (two of 203 districts). Peru has seen great success reducing childhood stunting<sup>29</sup>, in part due to its targeted focus on those most in need—the poor, the more disadvantaged and rural populations—and some of this progress is mirrored in its low rates of anemia as demonstrated by half of its districts (57.9%; 113 of 195) having less than 5% mean overall anemia prevalence in 2018.

With few exceptions, we see that countries with the subnational units with the best anemia prevalence rates in 2000 continue to have administrative units that perform well in 2018, and likewise for countries with the worst-performing subnational units. To illustrate where these high and low pockets continue to be most pervasive and how their rates of change contribute to maintaining this relative status, we overlaid the highest and lowest deciles for prevalence (Fig. 1a,b) and AROCs (Fig. 1d) for overall anemia among WRA across LMICs to simultaneously show the best- and worst-performing districts as defined by both of these measures over the study period (Fig. 1c). Much of Central and South America had districts with the lowest levels of prevalence of overall anemia in 2000 and 2018, with some areas experiencing the largest decreases over time (largest AROCs), including in western Colombia and central and southern Peru. Much of Mexico and El Salvador, as well as districts in western Honduras, central Ecuador and select districts in eastern Brazil, also had among the lowest prevalence levels in both years, whereas western Bolivia and western Guatemala experienced some of the largest declines in the period that led to their place among the lowest decile of anemia prevalence in 2018. Within these same countries, however, there were also districts with the highest prevalence levels and/or largest increases or stagnating trends in anemia (smallest AROC) between 2000 and 2018. Districts in southern Mexico, eastern Honduras, eastern Venezuela and eastern Colombia had among the lowest prevalence levels in 2000, but increases pushed these districts out of the lowest prevalence decile by 2018. Eastern Guatemala, eastern Ecuador and northern Bolivia had among the highest prevalence levels in both 2000 and 2018. In Asia, northern Vietnam and large stretches of China experienced some of the largest declines and had the lowest levels of anemia prevalence. Districts throughout Uzbekistan, Pakistan, India and Papua New Guinea and in northern Myanmar, however, saw the highest consistent prevalence, and the centers of Laos and India and parts of Afghanistan experienced among the largest increases or stagnating trends (smallest



**Fig. 1 | Prevalence and AROCs of overall anemia in WRA (2000–2018).** **a, b**, Prevalence of overall anemia among WRA (ages 15–49) at the second administrative unit (for example, district) level in 2000 (**a**) and 2018 (**b**). **c**, Overlapping population-weighted highest and lowest (10th and 90th deciles) prevalence and AROCs between 2000 and 2018. Largest AROC indicates where largest decreases in overall anemia prevalence from 2000 to 2018 occurred, whereas smallest AROC indicates where the largest increases (or smallest decreases or stagnation) in overall anemia prevalence from 2000 to 2018 occurred. **d**, Weighted annualized percentage of change of overall anemia prevalence in WRA from 2000 to 2018. Maps reflect administrative boundaries, land cover, lakes and population; gray-colored grid cells had fewer than ten people per  $1 \times 1$ -km grid cell and were classified as ‘barren or sparsely vegetated’, whereas white-colored grid cells were not included in this analysis<sup>42–47</sup>.



**Fig. 2 | Prevalence of anemia in WRA by severity in LMICs (2000 and 2018).** a–f, Prevalence of anemia stratified by severity among WRA (ages 15–49) at the second administrative unit (for example, district) level. Prevalence of mild anemia among WRA in 2000 (a) and 2018 (d). Prevalence of moderate anemia among WRA in 2000 (b) and 2018 (e). Prevalence of severe anemia among WRA in 2000 (c) and 2018 (f). See Supplementary Table 7 for the cutoffs defining mild, moderate and severe anemia. Maps reflect administrative boundaries, land cover, lakes and population; gray-colored grid cells had fewer than ten people per  $1 \times 1$ -km grid cell and were classified as ‘barren or sparsely vegetated’, whereas white-colored grid cells were not included in this analysis<sup>42–47</sup>.

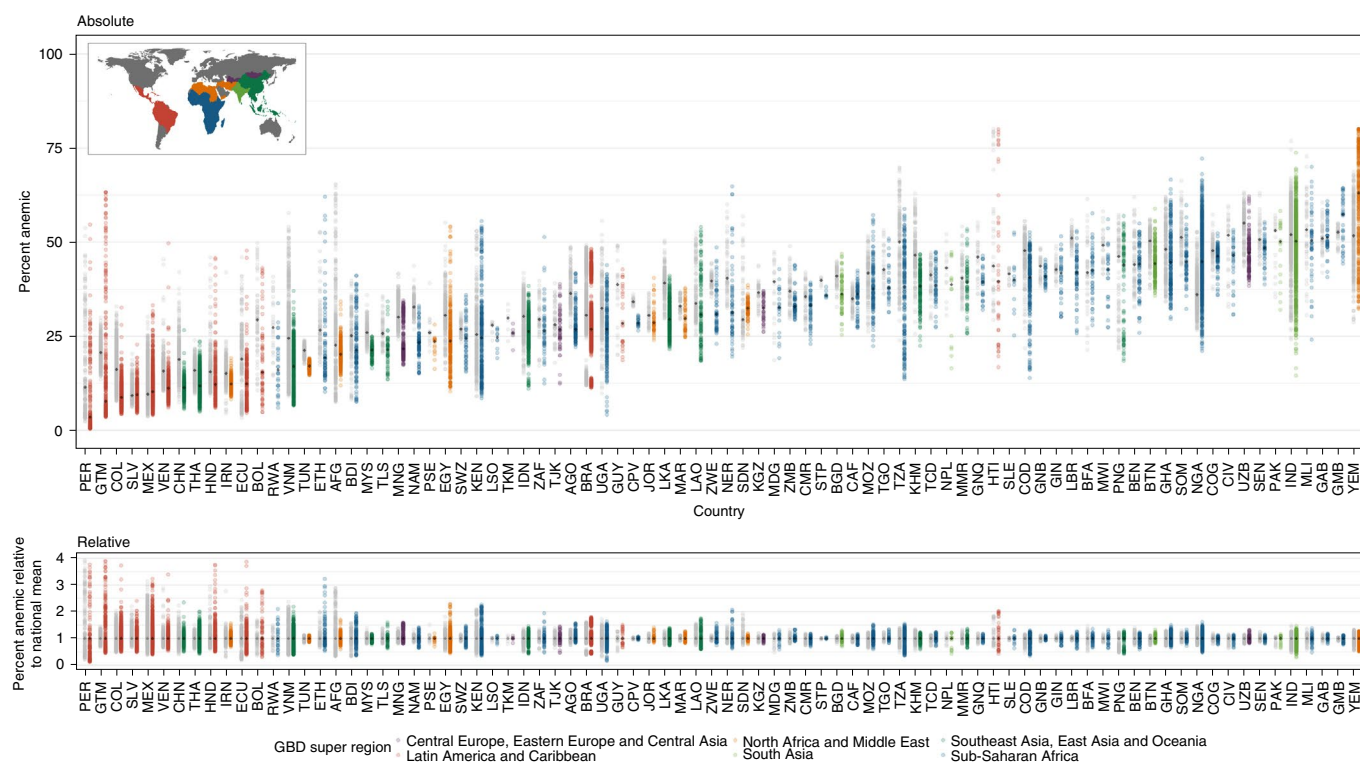
AROC). Several African countries had among the highest levels of anemia in both years, including Senegal, Mali, Côte d’Ivoire, eastern Ghana, southern Benin, central Niger, Nigeria, Gabon, Democratic Republic of the Congo, Tanzania, Kenya, Ethiopia, Somalia, Malawi, Mozambique, Zimbabwe and Egypt, and the belt across the Sahel witnessed some of the worst stagnation. No African districts ranked among the lowest decile of anemia prevalence, but there were areas in Ethiopia, Tanzania, Democratic Republic of the Congo, South Africa and a few other select districts that experienced some of the fastest decreases.

Overall, 71 (86.6%) LMICs experienced decreases in mean anemia prevalence in most of their districts over the 2000–2018 period, and seven (8.5%) LMICs (Cape Verde, China, Kyrgyzstan, Malaysia, Namibia, Tunisia and Turkmenistan) had annualized improvements (declines) in all districts. Increases in overall anemia prevalence were experienced in the majority of districts in nine LMICs (Burundi, Central African Republic, Côte d’Ivoire, Gabon, Gambia, Nigeria, Republic of the Congo, Tajikistan and Yemen), and no countries experienced increases in all their districts. Many countries experienced extreme differences in their rates of change across their subnational units: 57 (69.5%) LMICs had at least 2.5% annualized decreases and increases across their districts, whereas 18 (22.0%) LMICs had districts with at least 5% AROC in both directions.

**Prevalence and trends of anemia by severity.** Mean prevalence of moderate and severe anemia had reduced in the majority (84.1%; 18,441 of 21,917) of districts across LMICs between 2000 and 2018 (Fig. 2). In almost a quarter of the districts in which moderate and severe anemia had declined (24.5%; 4,526 of 18,441 across 79 LMICs), mild anemia had increased, indicating a downward shift in severity levels over the populations. Among these, three-quarters (76.0%; 3,476 of 4,562) saw decreases in overall anemia, suggesting an overall shift toward normal levels of hemoglobin regardless of

the historical baseline and in spite of the observed increased prevalence of mild anemia. This is further corroborated by the remaining 13,915 districts, which experienced decreases in moderate, severe and mild anemia. Among the districts that saw increases in prevalence of moderate and severe anemia (15.9%; 3,476 of 21,917), 91.3% (3,175 of 3,476 in 57 LMICs) experienced increases in overall anaemia, indicating a population-wide shift toward reduced hemoglobin levels. This was seen particularly in Yemen and Nigeria, where 81.7% (272 of 333) and 68.8% (533 of 775) of their districts, respectively, saw increases in overall, moderate and severe anemia. In contrast, only 276 districts saw increases in moderate and severe anemia but decreases in overall anemia, possibly indicating a sub-population that has been left behind while the majority trend is toward non-anemic hemoglobin levels. Of note, Papua New Guinea and Burkina Faso experienced this divergent trend where 11.5% (10 of 87) and 11.1% (5 of 45) of their districts, respectively, saw increases in the prevalence of moderate and severe anemia while overall anemia decreased. Our stratified maps of the highest- and lowest-decile districts for prevalence and AROC for mild, moderate and severe anemia offer a detailed view of these shifts in severity across and within LMICs over time (Extended Data Fig. 1).

**Absolute and relative geographic inequalities of anemia.** In addition to the overall trend toward lower levels of anemia prevalence, the heterogeneity of district-level anemia prevalence and, thus, subnational inequality has decreased over the last two decades. By plotting the absolute geographic inequalities (Fig. 3a), we show the range of overall anemia prevalence among each country’s districts in 2000 and 2018. Subnational inequalities between districts with the highest and lowest anemia prevalence in each country have increased in most (65.9%; 54 of 82) LMICs over the study period. Absolute inequalities among districts as well as national median anemia prevalence increased in six countries during the period from 2000



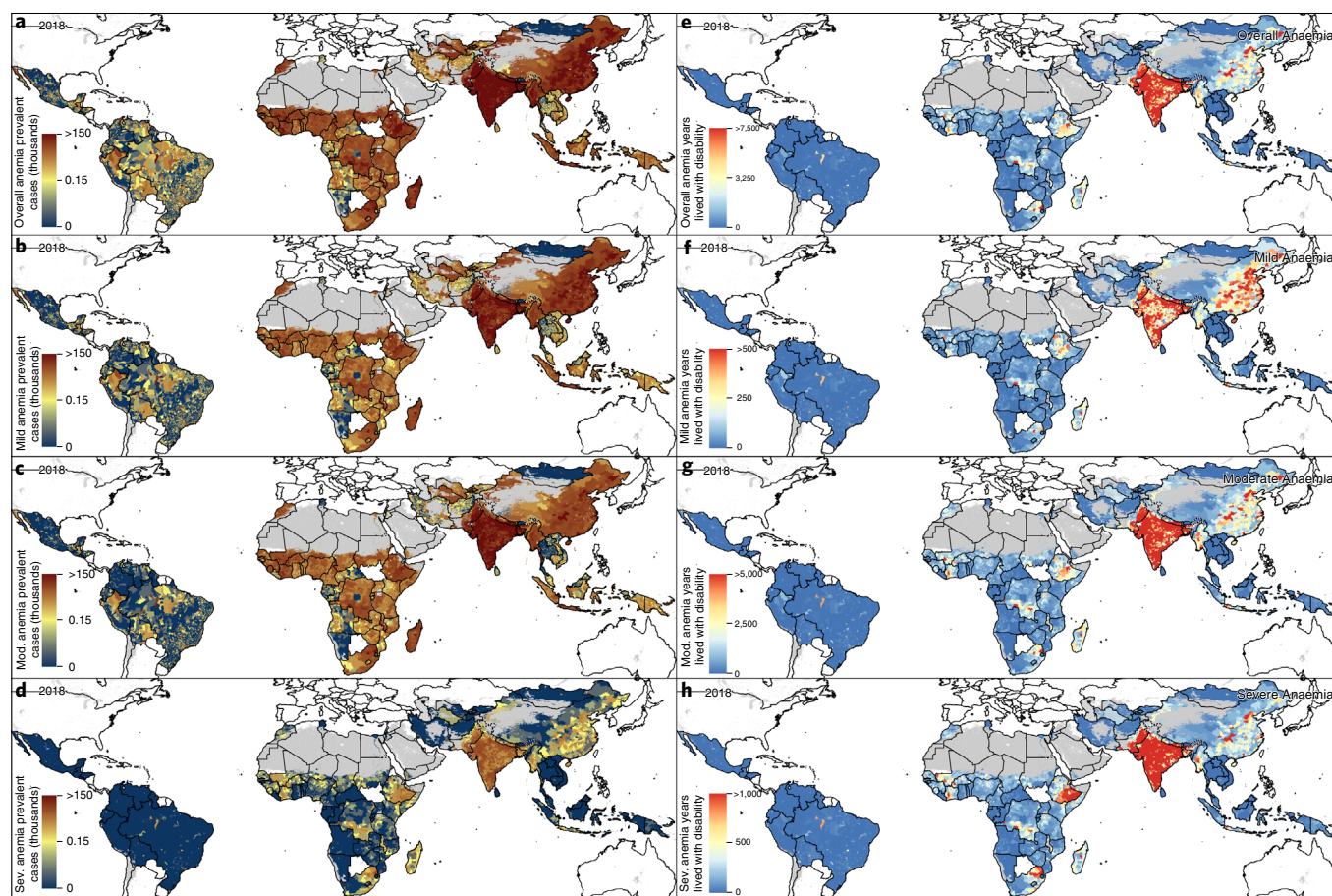
**Fig. 3 | Geographical inequality in overall anemia among WRA across 82 countries for 2000 and 2018. a**, Absolute inequalities: range of overall anemia estimates in WRA in second administrative-level units within 82 LMICs. **b**, Relative inequalities: range of ratios of overall anemia estimates in WRA in second administrative-level units relative to country means (administrative level/country level). Each dot represents a second administrative-level unit. The lower bound of each bar represents the second administrative-level unit with the lowest overall anemia in WRA in each country. The upper end of each bar represents the second administrative-level unit with the highest overall anemia in WRA in each country. Thus, each bar represents the extent of geographic inequality in overall anemia in WRA estimated for each country. Bars indicating the range in 2018 are colored according to their GBD super-region<sup>48</sup> (Extended Data Fig. 3). Gray bars indicate the range in overall anemia in WRA in 2000. The black diamond in each bar represents the median and mean overall anemia in WRA estimated across second administrative-level units in each country and year for the absolute (median) and relative (mean) inequalities plots. A colored bar that is shorter than its gray counterpart indicates that geographic inequality has narrowed.

to 2018: Yemen (2.4-fold to 2.6-fold difference; 51.7% (34.0–68.6%) to 63.0% (50.9–74.3%) national median prevalence); Gambia (1.2-fold to 1.5-fold difference; 52.7% (30.4–74.7%) to 63.7% (47.4–66.2%)); Nigeria (2.0-fold to 3.4-fold difference; 36.1% (17.4–58.4%) to 44.8% (37.2–66.2%)); Central African Republic (1.3-fold to 1.6-fold difference; 35.0% (19.5–53.5%) to 36.2% (20.4–54.2%)); El Salvador (3.3-fold to 5.0-fold difference; 9.2% (4.6–16.8%) to 9.5% (3.1–21.4%)); and Gabon (1.4-fold to 1.5-fold difference; 51.0% (32.2–70.5%) to 51.2% (33.8–67.9%)). Although absolute inequalities had also increased in the other 48 LMICs, national median anemia prevalence decreased in these countries, indicating select exemplar districts that made progress and/or districts that were left behind in national progress. Overall, 28 LMICs reduced absolute inequalities as well as their national median anemia prevalence; most notably, China had reduced absolute inequalities from 5.6-fold to 4.7-fold across its districts, reducing its national median from 18.8% (10.2–30.9%) to 11.4% (4.4–22.7%) between 2000 and 2018. In 2000, 19 LMICs experienced  $\geq 3$ -fold difference in overall anemia, and six LMICs experienced  $\geq 6$ -fold difference in overall anemia (Afghanistan, Ecuador, Iran, Mexico, Peru and Vietnam); in 2018, 30 LMICs had  $\geq 3$ -fold difference, and 11 LMICs had  $\geq 6$ -fold difference, across districts (Bolivia, Colombia, Ecuador, Ethiopia, Guatemala, Honduras, Kenya, Mexico, Peru, Uganda and Venezuela) (Supplementary Table 10).

Our relative inequality plot shows the relative deviation of each country's districts from their national mean anemia prevalence (Fig. 3b). To elucidate these within-country differences, consider

that, in 2000, overall anemia prevalence varied across the national level by as much as 5.8-fold (9.5% (6.4–13.7%) in El Salvador; 55.5% (41.4–69.4%) in Gabon), and, in 2018, overall anemia varied by as much as 7.0-fold at the national level (8.2% (3.5–16.3%) in El Salvador; 57.4% (51.4–63.5%) in Yemen). Within-country relative inequalities in overall anemia increased in 63 LMICs between 2000 and 2018, with some of the most apparent deviations in Guatemala, Venezuela, Colombia, Ecuador, Bolivia, Thailand, Ethiopia, Egypt and Tajikistan; 19 LMICs experienced decreases in relative inequalities, including Iran, Vietnam, Palestine and Sudan. Although many of the countries with large subnational disparities in anemia prevalence could use the results from this study to efficiently target precision public health interventions where they are most needed, there is a second set of countries that had low subnational inequalities and high national prevalence, indicating a pervasive problem where ubiquitous intervention coverage is warranted. In 2018, among the 21 countries that qualified as high public health problems with a national mean overall anemia prevalence above 40%, four of these countries had low relative inequalities ranging from 75% to 125% of the national median: Gabon, Guinea-Bissau, Republic of Congo and Senegal.

**Population size, severity and disability burden of anemia.** Of the estimated 1.2 billion WRA across the 82 LMICs represented by our analysis in 2000, we estimate that 378.3 million (95% uncertainty interval: 308.0–456.0) (32.8% (26.7–39.5)) of WRA were anemic (Extended Data Fig. 2a). Of these, 178.4 million (134.6–231.8) or



**Fig. 4 |** Counts and YLDs by anemia severity among WRA across LMICs in 2018. **a–d**, Number of WRA across 82 LMICs with overall (**a**), mild (**b**), moderate (**c**) and severe (**d**) anemia in 2018 by second administrative-level units. **e–h**, Number of YLDs among WRA attributable to overall (**e**), mild (**f**), moderate (**g**) and severe (**h**) anemia in 2018 by second administrative-level units. Maps reflect administrative boundaries, land cover, lakes and population; gray-colored grid cells had fewer than ten people per 1×1-km grid cell and were classified as ‘barren or sparsely vegetated’, whereas white-colored grid cells were not included in this analysis<sup>42–47</sup>.

47.2% (43.7–50.8) were categorized as having mild anemia, whereas 182.4 million (138.1–234.5) or 48.2% (44.9–51.4) were moderate anemia cases, and 17.4 million (11.2–26.3) or 4.6% (3.6–5.8) were severe anemia cases (Extended Data Fig. 2b–d). In 2018, of the 1.5 billion WRA represented by our analysis, 449.1 million (382.4–526.9) (30.4% (25.9–35.6)) were estimated to be anemic—224.8 million (180.9–275.7) (50.1% (47.3–52.3%)) with mild cases of anemia, 208.1 million (173.1–247.3) (46.3% (45.3–46.9)) with moderate cases of anemia, and 16.1 million (12.2–21.3) (3.6% (3.2–4.0)) with severe cases of anemia (Fig. 4a–d).

A large proportion of anemic WRA were concentrated in a few countries in 2018; 83.0% (81.0–85.3) of overall anemia occurred in the Asian (61.7% (60.9–62.9)) and sub-Saharan African (21.3% (20.1–22.4)) regions (Fig. 4a). An estimated 59.6% (55.6–63.2) of anemic WRA, amounting to an estimated 267.5 million (241.5–293.2) cases across LMICs, lived in just four countries in 2018: India (181.3 million (171.4–190.2) cases; 40.4% (36.1–44.8) of anemia burden), China (39.5 million (32.3–46.9)); 8.8% (8.9–8.5)), Pakistan (23.8 million (15.3–32.6); 5.3% (4.0–6.2)) and Nigeria (23.0 million (22.5–23.5); 5.1% (5.9–4.5)). In 2018, we estimated that 65.2% (14,292 of 21,917) of districts contained fewer than 5,000 anemic WRA, 14.6% (3,199 of 21,917) with 5,000–14,999, 12.4% (2,716 of 21,917) with 15,000–49,999, 4.5% (991 of 21,917) with 50,000–150,000 and 1.7% (377 of 21,917) with 150,000–250,000, and 1.7% (374 of 21,917) had more than 250,000 WRA with any severity of anemia (Supplementary Table 12). The 374

districts that had more than 250,000 anemic WRA each were in 22 LMICs: Angola, Bangladesh, Brazil, Burkina Faso, Cameroon, China, Côte d’Ivoire, Democratic Republic of the Congo, Ethiopia, Ghana, Haiti, India, Indonesia, Madagascar, Morocco, Myanmar, Nepal, Pakistan, Peru, South Africa, Tanzania and Togo. Across the 1,545 first administrative-level units (hereafter ‘provinces’) in the 82 LMICs, 66 provinces located in 12 LMICs (Angola, Bangladesh, Brazil, China, Ethiopia, India, Indonesia, Myanmar, Nepal, Nigeria, Pakistan and South Africa) each had 1 million or more anemic WRA in 2018. All five of the provinces with the highest estimated number of WRA with anemia in 2018 were in India and Pakistan: Uttar Pradesh in India (29.0 million (26.3–31.5)), Bihar in India (15.8 million (14.4–17.1)), West Bengal in India (15.5 million (14.4–16.6)), Maharashtra in India (15.4 million (13.4–17.2)) and Punjab in Pakistan (12.6 million (6.8–18.8)).

Stratifying by severity, an estimated 57.9% (55.1–60.9) of moderately or severely anemic WRA lived in only three countries in 2018: India (103.4 million (94.2–112.7) cases; 46.1% (41.9–50.8%) of moderate or severe WRA anemia cases), Pakistan (13.4 million (8.5–19.0) cases; 6.0% (4.6–7.1%)) and China (13.0 million (10.2–16.5) cases; 5.8% (5.5–6.1%)) (Fig. 4c,d). We found that 133 districts had more than 250,000 WRA with moderate or severe anemia in 2018, located in nine LMICs: Bangladesh (two districts), Brazil (one district), China (one district), Côte d’Ivoire (one district), Democratic Republic of the Congo (one district), India (118 districts), Nepal (one district), Pakistan (seven districts) and Peru

(one district). The five provinces with the highest estimated numbers of moderate or severe WRA in 2018 were also all in India and Pakistan: Uttar Pradesh in India (16.7 million (14.7–19.0)), Bihar in India (9.4 million (8.4–10.5)), Maharashtra in India (8.2 million (6.7–9.8)), West Bengal in India (8.1 million (7.2–9.2)) and Punjab in Pakistan (6.9 million (3.7–10.6)).

Multiplying counts in each anemia severity category with the appropriate disability weights from the GBD study<sup>30</sup> allowed us to visualize where the majority of YLDs (attributable burden) due to anemia among WRA have been most concentrated in LMICs and how it has reduced over time (Extended Data Fig. 2e–h and Fig. 4e–h). Overall anemia contributed 12.7 million (5.9–22.2) YLDs in 2000, with 0.7 million (0.3–1.1), 9.4 million (4.7–15.4) and 2.6 million (0.9–5.7) YLDs from mild, moderate and severe anaemia, respectively (Extended Data Fig. 2e–h). By 2018, YLDs had increased to 14.0 million (9.0–20.4) overall; mild, moderate and severe anaemia increased to 0.8 million (0.5–1.3), 10.7 million (7.2–15.1) and reduced to 2.4 million (1.3–4.1) YLDs, respectively (Fig. 4e–h). In 2018, 0.7% (145 of 21,917) of districts each contributed more than 15,000 YLDs due to overall anemia among WRA; these districts were in just nine LMICs: Bangladesh, Brazil, China, Côte d'Ivoire, Democratic Republic of the Congo, India, Nepal, Pakistan and Peru. Districts with over 5,000 YLDs attributed to overall anemia among WRA (3.1% (677 of 21,917)) were in 33 LMICs. The three countries with the most YLDs from overall anemia among WRA in 2018 were India (6.43 million (5.80–7.11) YLDs), Pakistan (0.85 million (0.53–1.21) YLDs) and China (0.83 million (0.65–1.06) YLDs). In 2018, 532 of 21,917 districts across 30 LMICs contributed more than half of YLDs (7.0 million (4.8–9.6)) attributed to overall anemia across the 82 LMICs in this analysis.

Between 2000 and 2018, the majority of districts across LMICs experienced reductions in estimates of YLDs attributable to moderate anemia (54.1%; 11,859 of 21,917 districts) and severe anemia (67.9%; 14,876 of 21,917 districts) among WRA (Extended Data Fig. 2g,h and Fig. 4g,h). This progress in reducing YLDs due to moderate and severe anemia was especially evident in China (1.74 million (1.40–2.17) YLDs in 2000 and 0.74 million (0.57–0.95) in 2018; declines in 359 of 364 districts). In 10,078 districts located across all 82 LMICs, however, YLDs from moderate anemia increased, including in 12 countries where all districts experienced increases: Burkina Faso, Chad, Côte d'Ivoire, Guinea-Bissau, Jordan, Mali, Pakistan, São Tomé and Príncipe, Senegal, Sierra Leone, Somalia and Yemen. The YLDs from severe anemia increased in 7,061 districts across 79 LMICs, including in Yemen (332 of 333 districts), Burkina Faso (44 of 45 districts), Chad (53 of 55 districts) and Jordan (48 of 52 districts). The district with the largest increase in YLDs from moderate anemia was Bangalore (Karnataka) in India, with 23,003 (7,665–44,041) YLDs in 2000 and 43,497 (30,063–57,816) YLDs in 2018. The largest increase in YLDs from severe anemia was in Bijnor (Uttar Pradesh) in India, with 791 (282–1,627) YLDs in 2000 and 6,884 (4,767–9,476) YLDs in 2018.

**Prospects of meeting 2030 WHO GNT.** We applied the estimated AROCs to the final year of our estimates to predicted anemia prevalence estimates for the year 2030 (Fig. 5a). In 2018, 29 of 21,917 districts had >80% mean prevalence of overall anemia; if current trends continue, 100 districts across Guatemala (11 districts), Haiti (seven districts), India (two districts), Nigeria (four districts) and Yemen (76 districts) are estimated to reach >80% mean prevalence for overall anemia among WRA by 2030. Subnational inequalities in Guatemala are expected to continue, and, although 17 northeastern districts are projected to reach >75% prevalence by 2030, 179 southwestern districts are expected to reduce to below 5% prevalence, considered acceptable levels of anemia. Including Guatemala, we estimate that districts in 15 LMICs will have less than 5% prevalence in overall anemia by 2030: Afghanistan (1 of 399 districts), Bolivia

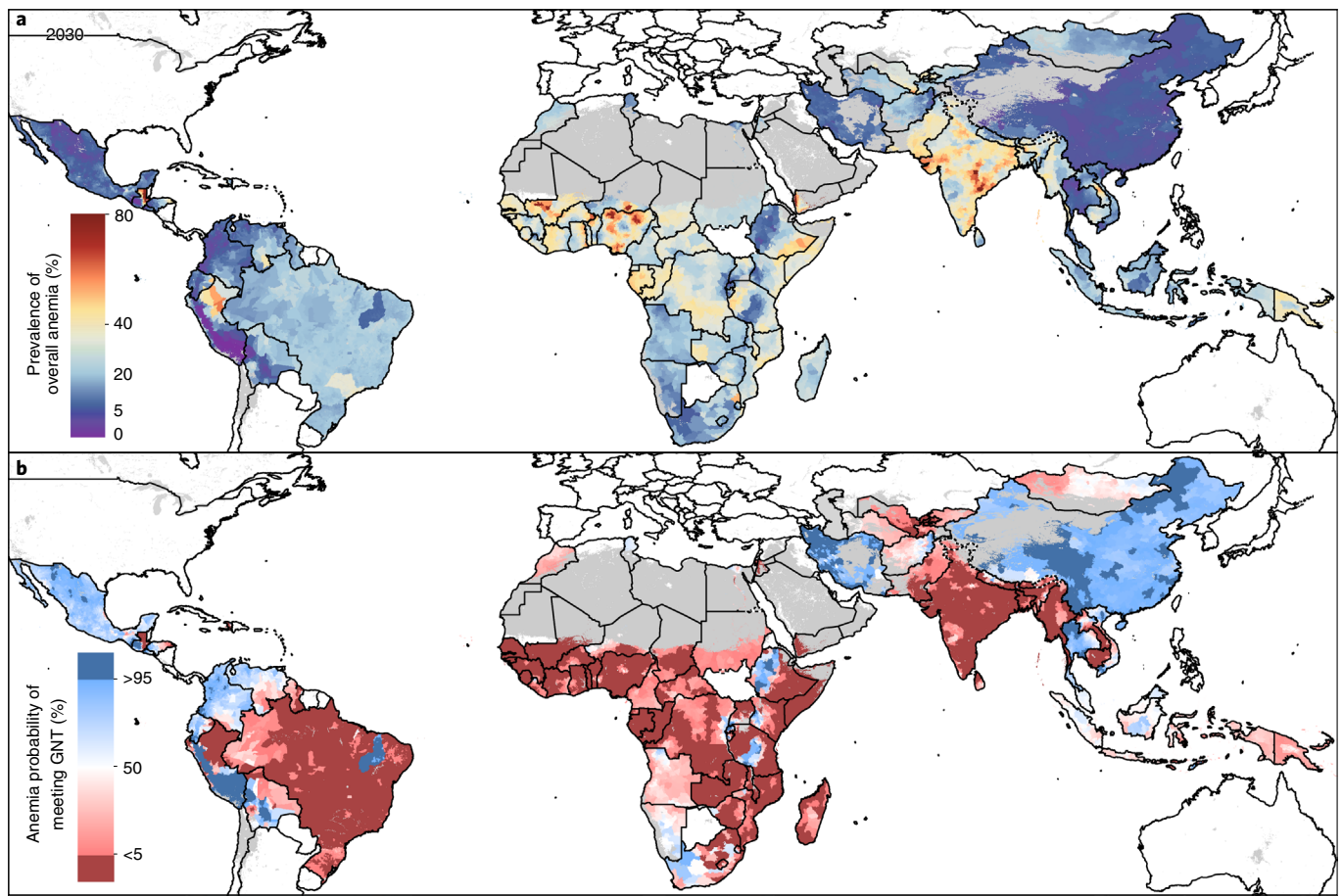
(16 of 117), China (2 of 364), Colombia (123 of 1,065), Ecuador (1 of 223), El Salvador (32 of 266), Guatemala (179 of 354), Honduras (13 of 298), Mexico (31 of 2,454), Peru (120 of 195), Rwanda (3 of 30), Thailand (28 of 928), Uganda (4 of 203), Venezuela (1 of 338) and Vietnam (1 of 710). Based on current projections, we expect that 21 LMICs will maintain high national levels of overall anemia ( $\geq 40\%$ ) in 2030; on a subnational scale, 16.4% (3,594 of 21,917) of districts located in 61 LMICs are estimated to have  $\geq 40\%$  anemia prevalence in 2030 if existing trajectories continue.

Assuming that recent trends persist, and using the year 2012 (the year that WHO GNTs were established) as a baseline, we estimated the probability of subnational units across LMICs achieving the WHO GNT to relatively reduce anemia by 50% by the year 2030 (Fig. 5b). By 2030, only three of the 82 (3.7%) LMICs in this analysis are expected to achieve the target of 16.2% at a national scale with a high probability (>95% posterior probability): China, Iran and Thailand. Subnationally, however, no countries have a high probability of meeting the WHO GNT for anemia in all provinces, nor in all their districts, by the target year. About a third (31.7%; 26 of 82) of LMICs have a high probability (>95%) of meeting the target in at least one district, whereas only three LMICs (Guatemala, Iran and Peru) have a high probability of meeting the goal in most districts. We expect far more LMICs to have a low probability (<5% posterior probability) of achieving the target nationally and subnationally. By 2030, 64.6% (53 of 82) of LMICs have a low probability (<5%) of meeting the WHO GNT nationally, whereas 21.2% (18) have a low probability in all provinces, and four LMICs (Gabon, Gambia, Senegal and Togo) have a low probability of meeting the target in all their districts. Although 15 (18.3%) LMICs have a >50% probability of achieving the WHO GNT by 2030 nationally, five (6.1%) LMICs have >50% probability of achieving the target in all their province-level units, and only Tunisia has >50% probability of meeting the goal in all its district-level units by 2030.

Large inequalities in achieving the WHO GNT are expected to continue, and 56.1% (46 of 82) of LMICs are predicted to have districts with both >50% and <50% probability of meeting the goal by 2030. We estimate that 20 LMICs have districts with both high probability (>95%) and low probability (<5%) of achieving the WHO GNT by 2030.

## Discussion

Marginal declines in anemia prevalence among WRA in LMICs have left individuals, populations and nations at risk of reduced economic productivity<sup>3,4</sup>, increased all-cause mortality<sup>5</sup> and increased potential for adverse outcomes for mothers and newborns<sup>31</sup>. Although most district-level units (80.5%; 17,651 of 21,917 districts) decreased their prevalence between 2000 and 2018, the overall prevalence among the 82 LMICs in our analysis has only declined, from 35.6% (95% uncertainty interval: 25.9–46.6) to 31.6% (25.7–38.2) in the nearly 20-year period. Even for the many countries with overall improvements in reducing anemia prevalence, our results highlight enduring disparities across global geographic regions and within select countries and subnational locations that have stagnated or fallen behind the general improvements of their neighbors. Although three LMICs (China, Iran and Thailand) have a high probability of meeting the WHO GNT of reducing anemia among WRA by 50% by the year 2030, no LMIC is predicted to meet the target in all provinces or all districts. Most LMICs (64.6%; 53 LMICs) have a low probability (<5%) of meeting the target even on a national scale. Broad inequalities are expected to continue into 2030; we estimate that 20 LMICs have districts with a high probability of meeting the target as well as districts with a low probability of meeting the target. Furthermore, population growth during this period has led to substantial increases in the number of WRA affected by anemia in various locations. Although the overall number of prevalence of anemia in WRA has decreased, growing popu-



**Fig. 5 | Prevalence for overall anemia among WRA in 2030 and probability of achieving the WHO GNT for overall anemia by 2030. a,** Predicted prevalence of overall anemia among WRA in 2030 by second administrative-level units. **b,** Probability of achievement of the WHO GNT to reduce overall anemia in WRA by 50% by the year 2030, with the year 2012 as a baseline, by second administrative-level units. Maps reflect administrative boundaries, land cover, lakes and population; gray-colored grid cells had fewer than ten people per  $1 \times 1$ -km grid cell and were classified as 'barren or sparsely vegetated' or were not included in this analysis<sup>42–47</sup>.

lations have caused the number of anemic WRA to increase from 378.3 million to 449.1 million, with the largest increases in Central Asia and western, central and eastern sub-Saharan Africa (54.7% increase: 20.2–31.3 million; 88.0% increase: 24.6–46.2 million; 53.1% increase: 7.6–11.6 million; and 51.8% increase: 20.9–31.8 million, respectively), offsetting the large decreases seen in East Asia and Andean South America (44.1% decrease: 70.9–39.6 million and 13.7% decrease: 5.6–4.8 million, respectively).

The multitude of different diseases and injuries, nutritional and behavioral risk factors and sociodemographic factors that can lead to anemia mandate inter- and multi-sectorial approaches involving stakeholders and actors in the public and private sectors and coordination across food systems and health-related sectors if large-scale reductions in anemia prevalence are to be achieved<sup>2,16</sup>. GBD 2019 estimated the top-ranked global causes of anemia in WRA to be, in order, dietary iron deficiency; thalassaemia trait; sickle cell trait; menstrual disorders; endocrine, metabolic, blood and immune disorders; and malaria<sup>19</sup>, although the specific cause composition varied by country and age group. Regardless of anemia prevalence levels, the WHO recommends a diet with adequate bio-available iron and iron folate and micronutrient fortification of rice and flours where they are major staples<sup>16</sup>. Intermittent or daily iron and folic acid supplementation is recommended for WRA depending on pregnancy and postpartum status, menstruation, tuberculosis diagnosis and population-level prevalence, with key prevalence thresholds of 20% and 40%<sup>16</sup>. Research suggests that multiple

micronutrient supplementation for pregnant women in LMICs might provide additional benefits of reducing low-birth-weight outcomes, small-for-gestational-age outcomes and preterm birth outcomes<sup>32</sup>. Universal antenatal hemoglobin testing can help identify anemic women early, providing time to investigate causality and eliminate anemia before delivery<sup>33</sup>. In endemic areas, malaria control has demonstrated over 25% and 60% reduction in overall anemia and severe anaemia, respectively<sup>16</sup>. Countries with high levels of anemia and malaria<sup>34</sup>, such as Mali, Democratic Republic of the Congo, Papua New Guinea, Pakistan and India, might benefit from increased malaria control efforts. Proper water and sanitation, including safe water and education on hand-washing and hygienic disposal of fecal matter, can reduce infection risks and related nutritional losses<sup>2</sup>. Additionally, the association between intestinal helminths and anemia, due to nutritional theft and direct blood loss, has led the WHO<sup>35</sup> to recommend de-worming pregnant women in helminth-endemic areas. LMICs with co-distribution of helminths<sup>36</sup> and high prevalence of anemia include Nigeria, Madagascar, Bangladesh and Papua New Guinea. A variety of intervention delivery platforms could be used, including regular routine antenatal care visits, community health workers and community-based social marketing<sup>16</sup>. Strategies and delivery platforms should be context-specific and tailored for populations based on the local culture and disease burden; these estimates provide policy-makers the opportunity to 'aim to ensure the most vulnerable members of the populations are reached'<sup>16</sup>. For those with chronic conditions, such



as sickle cell disease, thalassaemia, inflammatory bowel disease, endocrine disorders or chronic kidney disease, more nuanced and potentially more intensive treatments are likely to be required to manage the underlying disease and reduce anemia burden.

Future research could cross-reference our estimates with implemented policies by location to determine effective strategies and exemplars of progress to further aid policy-makers and decision-makers. Although the models used in this study are not inherently inferential, the complex, yet still relatively predictable, pathways that lead to anemia suggest that those populations with a high burden of anemia are also highly likely to have a high burden of the diseases that cause anemia and are likely to be suffering from multiple simultaneous deprivations of nutrition, economics, health systems and overall resilience. We have seen success, as evidenced in Peru, in using targeted programs to reach those most in need, and understanding where they might be is a prerequisite toward analogous future campaigns against anemia and many other inequitable global health crises. These maps thus provide a roadmap to identifying the most vulnerable populations in the world and can be viewed concurrently with our previous work tracking progress and/or predictions of meeting other WHO GNTs—including geospatial annual estimates of exclusive breastfeeding<sup>25</sup>, childhood overweight and wasting<sup>37</sup> and childhood stunting, wasting and underweight<sup>26,27</sup>—as well as estimates of child diarrhea<sup>38</sup>, child mortality<sup>39</sup>, malaria<sup>34</sup>, inherited blood disorders (for example, sickle cell diseases<sup>40</sup>), helminths<sup>36</sup> and food system sustainability<sup>41</sup> to gain a more complete view of the needs of specific countries and communities.

Although this study sheds light on the varied levels of anemia across countries, the unequal levels within them and the varied rates of progress that have led them to their status, it is not without limitations. Most notably, the accuracy of these estimates is predicated on the quality and the quantity of the underlying data. We have invested substantial effort in building a geo-located database of over 3 million women for the purpose of this analysis, but large gaps in both the spatial and temporal data coverage remain. Supplementary Figs. 6 and 7 show the number of years of data underpinning each administrative level-one and level-two unit in the analysis, and Supplementary Figs. 1–5 illustrate the spatial resolution and temporal location of this data. The uncertainty of these estimates, shown in Supplementary Figs. 10–13, is largely driven by the consistency and volume of the data and, at times, can be quite high. Our validation analysis shows that our model is well-calibrated with minimal bias and good coverage of the 95% prediction intervals, demonstrating that the uncertainty of the estimates is appropriate given the data. To improve the precision of these estimates, increases in data collection and reporting will be needed, and the uncertainty maps provide a starting point for adaptive sampling techniques that can target areas that we uncertainly estimate to have high risk.

Combined with the lack of necessary data that would be needed to perform high-resolution mapping of the conditions that cause anemia, our analysis and some of its limitations underscore the challenges in large-scale global reduction of anemia. Venous sampling of whole blood followed by assessment via automated hematology analyzers is considered the gold standard measurement, but most population-based surveys use capillary samples and the HemoCue colorimetric point-of-care tool to measure hemoglobin concentration and assess population prevalence of anemia. There are documented differences in the concentration of hemoglobin in venous blood samples compared to capillary blood samples, but the direction and consistency of the error introduced by capillary measurement has not been definitively established. We did not have sufficient data to stratify by the mode of assessment in each country at the local level. In addition, we did not estimate anemia by underlying cause, which limits the precision with which we can make specific statements about likely appropriateness of specific interventions for specific locations, although we do expect the epidemiology

of anemia to track with the underlying causes of anemia. Similarly, prevalence and count maps of all-anemia burden can be used to target hotspots but are not sufficient to determine the best course of treatment for those communities. Neither the uncertainty from resampling polygonal data to point data, nor the uncertainty from modeled covariates, were accounted for in our models. Uncertainty plots of the outputs in our models can be found in Supplementary Figs. 10–13 and 16. We expect that propagating the uncertainty from the resampling and the modeled covariates would increase the overall uncertainty in our estimates. In contrast, if we were able to incorporate the assessment technique (venous versus capillary) or the processing technique, we expect that accounting for these possible confounders would decrease the uncertainty of these estimates.

The large global burden of anemia continues to underline the need for high-resolution estimates to track progress toward international targets and to aid policy-makers in targeting interventions and scarce resources. The recent addition of anemia reduction as a target for the Sustainable Development Goal 2 further highlights the global importance of the issue<sup>22,23</sup>. This study details the subnational trends in anemia prevalence in WRA across 82 LMICs, broken down by severity, and highlights the local differences in burden and progress within and between countries. The results and the interactive visualizations presented in this study provide an unprecedented opportunity for policy-makers and health institutes to examine the variation in anemia prevalence and its historical progress within their communities and can aid targeting of further data collection, limited resources and interventions to populations most in need.

### Online content

Any methods, additional references, Nature Research 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/s41591-021-01498-0>.

Received: 3 June 2020; Accepted: 10 August 2021;

Published online: 12 October 2021

### References

1. Kassebaum, N. J. & GBD 2013 Anemia Collaborators. The Global Burden of Anemia. *Hematol. Oncol. Clin. North Am.* **30**, 247–308 (2016).
2. World Health Organization. Global nutrition targets 2025: anaemia policy brief. <https://apps.who.int/iris/handle/10665/148556> (2014).
3. Haas, J. D. & Brownlie, T. Iron deficiency and reduced work capacity: a critical review of the research to determine a causal relationship. *J. Nutr.* **131**, 676S–690S (2001).
4. Horton, S. & Ross, J. The economics of iron deficiency. *Food Policy* **28**, 51–75 (2003).
5. Martinsson, A. et al. Anemia in the general population: prevalence, clinical correlates and prognostic impact. *Eur. J. Epidemiol.* **29**, 489–498 (2014).
6. Smith, E. R. et al. Modifiers of the effect of maternal multiple micronutrient supplementation on stillbirth, birth outcomes, and infant mortality: a meta-analysis of individual patient data from 17 randomised trials in low-income and middle-income countries. *Lancet Glob. Health* **5**, e1090–e1100 (2017).
7. Kavle, J. A. et al. Association between anaemia during pregnancy and blood loss at and after delivery among women with vaginal births in Pemba Island, Zanzibar, Tanzania. *J. Health Popul. Nutr.* **26**, 232–240 (2008).
8. CHERG Iron Report: Maternal Mortality, Child Mortality, Perinatal Mortality, Child Cognition, and Estimates of Prevalence of Anemia due to Iron Deficiency. Global Health Data Exchange. <http://ghdx.healthdata.org/record/chergh-iron-report-maternal-mortality-child-mortality-perinatal-mortality-child-cognition-and>
9. Davis E. & Sparzak P. B. Abnormal uterine bleeding. *StatPearls*. <https://www.ncbi.nlm.nih.gov/books/NBK532913/> (2021).
10. Stein, J. et al. Anemia and iron deficiency in gastrointestinal and liver conditions. *World J. Gastroenterol.* **22**, 7908–7925 (2016).
11. White, N. J. Anaemia and malaria. *Malar. J.* **17**, 371 (2018).
12. Calis, J. C. J. et al. Erythropoiesis in HIV-infected and uninfected Malawian children with severe anemia. *AIDS* **24**, 2883–2887 (2010).

13. Alamo, I. G. et al. Characterization of erythropoietin and hepcidin in the regulation of persistent injury-associated anemia. *J. Trauma Acute Care Surg.* **81**, 705–712 (2016).
14. Semba, R. D. & Bloem, M. W. The anemia of vitamin A deficiency: epidemiology and pathogenesis. *Eur. J. Clin. Nutr.* **56**, 271–281 (2002).
15. Black, A. K., Allen, L. H., Pelto, G. H., de Mata, M. P. & Chávez, A. Iron, vitamin B-12 and folate status in Mexico: associated factors in men and women and during pregnancy and lactation. *J. Nutr.* **124**, 1179–1188 (1994).
16. World Health Organization. Nutritional anaemias: tools for effective prevention and control. <https://apps.who.int/iris/handle/10665/259425> (2017).
17. Girard, A. W., Self, J. L., McAuliffe, C. & Olude, O. The effects of household food production strategies on the health and nutrition outcomes of women and young children: a systematic review. *Paediatr. Perinat. Epidemiol.* **26**, 205–222 (2012).
18. Dicker, D. et al. Global, regional, and national age-sex-specific mortality and life expectancy, 1950–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet* **392**, 1684–1735 (2018).
19. Institute for Health Metrics and Evaluation. GBD Compare. <https://vizhub.healthdata.org/gbd-compare/>
20. World Health Organization. Global targets tracking tool. <https://www.who.int/tools/global-targets-tracking-tool> (2019).
21. WHO/UNICEF Discussion Paper. The extension of the 2025 Maternal, Infant and Young Child nutrition targets to 2030. <https://www.who.int/nutrition/global-target-2025/discussion-paper-extension-targets-2030.pdf?ua=1> (2018).
22. Sustainable Development Solutions Network. Indicators and a Monitoring Framework. Goal 02. End hunger, achieve food security and improved nutrition, and promote sustainable agriculture. <https://indicators.report/goals/goal-2/>
23. Leone, F. New Indicators on AMR, Dispute Resolution, GHG Emissions Agreed for SDG Framework. IISD SDG Knowledge Hub. <https://sdg.iisd.org/443/news/new-indicators-on-amr-dispute-resolution-ghg-emissions-agreed-for-sdg-framework/> (2019).
24. World Health Organization. The global prevalence of anaemia in 2011. [http://www.who.int/entity/nutrition/publications/micronutrients/global\\_prevalence\\_anaemia\\_2011/en/index.html](http://www.who.int/entity/nutrition/publications/micronutrients/global_prevalence_anaemia_2011/en/index.html) (2015).
25. Bhattacharjee, N. V. et al. Mapping exclusive breastfeeding in Africa between 2000 and 2017. *Nat. Med.* **25**, 1205–1212 (2019).
26. Osgood-Zimmerman, A. et al. Mapping child growth failure in Africa between 2000 and 2015. *Nature* **555**, 41–47 (2018).
27. Kinyoki, D. K. et al. Mapping child growth failure across low- and middle-income countries. *Nature* **577**, 231–234 (2020).
28. World Health Organization. Haemoglobin concentrations for the diagnosis of anaemia and assessment of severity. <https://www.who.int/vmnis/indicators/haemoglobin.pdf> (2011).
29. Akseer, N., Vaivada, T., Rothschild, O., Ho, K. & Bhutta, Z. A. Understanding multifactorial drivers of child stunting reduction in *Exemplar* countries: a mixed-methods approach. *Am. J. Clin. Nutr.* **112**, 792S–805S (2020).
30. GBD 2019 Risk Factors Collaborators. Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *Lancet* **396**, 1223–1249 (2020).
31. Rasmussen, K. Is there a causal relationship between iron deficiency or iron-deficiency anemia and weight at birth, length of gestation and perinatal mortality? *J. Nutr.* **131**, 590S–601S; discussion 601S–603S (2001).
32. Keats, E. C., Haider, B. A., Tam, E. & Bhutta, Z. A. Multiple-micronutrient supplementation for women during pregnancy. *Cochrane Database Syst. Rev.* **3**, CD004905 (2019).
33. Jose, A. et al. Comparison of ferric Carboxymaltose and iron sucrose complex for treatment of iron deficiency anemia in pregnancy—randomised controlled trial. *BMC Pregnancy Childbirth* **19**, 54 (2019).
34. Weiss, D. J. et al. Mapping the global prevalence, incidence, and mortality of *Plasmodium falciparum*, 2000–17: a spatial and temporal modelling study. *Lancet* **394**, 322–331 (2019).
35. Njua-Yafi, C. et al. Malaria, helminths, co-infection and anaemia in a cohort of children from Mutengene, south western Cameroon. *Malar. J.* **15**, 69 (2016).
36. Pullan, R. L. & Brooker, S. J. The global limits and population at risk of soil-transmitted helminth infections in 2010. *Parasites Vectors* **5**, 81 (2012).
37. Kinyoki, D. K. et al. Mapping local patterns of childhood overweight and wasting in low- and middle-income countries between 2000 and 2017. *Nat. Med.* **26**, 750–759 (2020).
38. Reiner, R. C. Jr. et al. Mapping geographical inequalities in childhood diarrhoeal morbidity and mortality in low-income and middle-income countries, 2000–2017: analysis for the Global Burden of Disease Study 2017. *Lancet* **395**, 1779–1801 (2020).
39. Burstein, R. et al. Mapping 123 million neonatal, infant and child deaths between 2000 and 2017. *Nature* **574**, 353–358 (2019).
40. The Malaria Atlas Project. *Inherited Blood Disorders*. <https://malariaatlas.org/research-project/blood-disorders/>
41. Béné, C. et al. Global map and indicators of food system sustainability. *Sci. Data* **6**, 279 (2019).
42. GeoNetwork. The Global Administrative Unit Layers (GAUL). <http://www.fao.org/geonetwork/srv/en/main.home> (2015).
43. Friedl, M. & Sulla-Menashe, D. MCD12Q1 v006: MODIS/Terra+ Aqua Land Cover Type Yearly L3 Global 500 m SIN Grid <https://doi.org/10.5067/MODIS/MCD12Q1.006> (2019).
44. World Wildlife Fund. Global Lakes and Wetlands Database, Level 3. <https://www.worldwildlife.org/pages/global-lakes-and-wetlands-database> (2004).
45. Lehner, B. & Döll, P. Development and validation of a global database of lakes, reservoirs and wetlands. *J. Hydrol.* **296**, 1–22 (2004).
46. WorldPop. Open Spatial Demographic Data and Research. <https://www.worldpop.org/>
47. Tatem, A. J. WorldPop, open data for spatial demography. *Sci. Data* **4**, 170004 (2017).
48. Murray, C. J. et al. GBD 2010: design, definitions, and metrics. *Lancet* **380**, 2063–2066 (2012).

**Publisher's note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/>.

© The Author(s) 2021

## Local Burden of Disease Anaemia Collaborators

Lauren E. Schaeffer<sup>5,6</sup>, Alice Lazzar-Atwood<sup>1</sup>, Dan Lu<sup>1</sup>, Samuel B. Ewald<sup>1</sup>, Katie M. Donkers<sup>1</sup>, Ian D. Letourneau<sup>1</sup>, Michael Collison<sup>1</sup>, Megan F. Schipp<sup>1</sup>, Amanuel Abajobir<sup>7</sup>, Sima Abbasi<sup>8</sup>, Nooshin Abbasi<sup>9</sup>, Mitra Abbasifard<sup>10,11</sup>, Mohsen Abbasi-Kangevari<sup>12</sup>, Hedayat Abbastabar<sup>13</sup>, Foad Abd-Allah<sup>14</sup>, Ahmed Abdelalim<sup>14</sup>, Sherief M. Abd-Elsalam<sup>15</sup>, Amir Abdoli<sup>16</sup>, Ibrahim Abdollahpour<sup>17</sup>, Aidin Abedi<sup>18</sup>, Hassan Abolhassani<sup>19,20</sup>, Biju Abraham<sup>21</sup>, Lucas Guimarães Abreu<sup>22</sup>, Michael R. M. Abrigo<sup>23</sup>, Ahmed Abualhasan<sup>14</sup>, Eman Abu-Gharbieh<sup>24</sup>, Abdelrahman I. Abushouk<sup>25,26</sup>, Manfred Mario Kokou Accrombessi<sup>27,28</sup>, Maryam Adabi<sup>29</sup>, Oladimeji M. Adebayo<sup>30</sup>, Adeyinka Emmanuel Adegbosin<sup>31</sup>, Victor Adekanmbi<sup>32</sup>, Olatunji O. Adetokunboh<sup>33,34</sup>, Daniel Adedayo Adeyinka<sup>35,36</sup>, Davoud Adham<sup>37</sup>, Shailesh M. Advani<sup>38,39</sup>, Pradyumna Agasthi<sup>40</sup>, Mohammad Aghaali<sup>41</sup>, Sohail Ahmad<sup>42</sup>, Tauseef Ahmad<sup>43</sup>, Keivan Ahmadi<sup>44</sup>,

Sepideh Ahmadi<sup>45</sup>, Muktar Beshir Ahmed<sup>46,47</sup>, Miloud Taki Eddine Aichour<sup>48</sup>, Budi Aji<sup>49</sup>,  
 Oluwaseun Oladapo Akinyemi<sup>50,51</sup>, Addis Aklilu<sup>52</sup>, Chisom Joyqueenet Akunna<sup>53,54</sup>, Ziyad Al-Aly<sup>55,56</sup>,  
 Turki M. Alanzi<sup>57</sup>, Jacqueline Elizabeth Alcalde-Rabanal<sup>58</sup>, Biresaw Wassihun Alemu<sup>59,60</sup>,  
 Ayinalem Alemu<sup>61</sup>, Robert Kaba Alhassan<sup>62</sup>, Sheikh Mohammad Alif<sup>63</sup>, Vahid Alipour<sup>64,65</sup>,  
 Hesam Alizade<sup>66</sup>, Syed Mohamed Aljunid<sup>67,68</sup>, Amir Almasi-Hashiani<sup>69</sup>, Hesham M. Al-Mekhlafi<sup>70,71</sup>,  
 Rajaa M. Al-Raddadi<sup>72</sup>, Nelson Alvis-Guzman<sup>73,74</sup>, Saeed Amini<sup>75</sup>, Fatemeh Amiri<sup>76</sup>,  
 Dickson A. Amugsi<sup>77</sup>, Nahla Hamed Anber<sup>77,78</sup>, Robert Ancuceanu<sup>79</sup>, Tudorel Andrei<sup>80</sup>,  
 Masresha Tessema Anegago<sup>81,82</sup>, Mina Anjomshoa<sup>83</sup>, Fereshteh Ansari<sup>84,85</sup>,  
 Alireza Ansari-Moghaddam<sup>86</sup>, Zelalem Alamrew Anteneh<sup>87</sup>, Ernoiz Antriyandarti<sup>88</sup>,  
 Davood Anvari<sup>89,90</sup>, Razique Anwer<sup>91</sup>, Muhammad Aqeel<sup>92</sup>, Jalal Arabloo<sup>64</sup>, Morteza Arab-Zozani<sup>93</sup>,  
 Olatunde Aremu<sup>94</sup>, Habtamu Abera Areri<sup>95</sup>, Al Artaman<sup>96</sup>, Afsaneh Arzani<sup>97,98</sup>, Malke Asaad<sup>99</sup>,  
 Mehran Asadi-Aliabadi<sup>100</sup>, Ali A. Asadi-Pooya<sup>101,102</sup>, Mulusew A. Asemahagn<sup>103</sup>,  
 Mohammad Asghari Jafarabadi<sup>104,105</sup>, Mengistu M. Ashebir<sup>106</sup>, Zerihun Ataro<sup>107</sup>,  
 Seyyede Masoume Athari<sup>108</sup>, Seyyed Shamsadin Athari<sup>109</sup>, Maha Moh'd Wahbi Atout<sup>110</sup>,  
 Marcel Ausloos<sup>80,111</sup>, Nefsu Awoke<sup>112</sup>, Beatriz Paulina Ayala Quintanilla<sup>113</sup>, Getinet Ayano<sup>114</sup>,  
 Martin Amogre Ayanore<sup>115</sup>, Yared Asmare Aynalem<sup>116</sup>, Muluken Altaye Ayza<sup>117</sup>, Abbas Azadmehr<sup>118</sup>,  
 Darshan B<sup>119</sup>, Tesleem Kayode Babalola<sup>120,121</sup>, Alaa Badawi<sup>122,123</sup>, Ashish D. Badiye<sup>124</sup>,  
 Mohammad Amin Bahrami<sup>125</sup>, Mohan Bairwa<sup>126</sup>, Shankar M. Bakkannavar<sup>127</sup>, Palash Chandra Banik<sup>128</sup>,  
 Adhanom Gebregziabher Baraki<sup>129</sup>, Miguel A. Barboza<sup>130,131</sup>, Huda Basaleem<sup>132</sup>, Sanjay Basu<sup>133,134</sup>,  
 Mohsen Bayati<sup>135</sup>, Bayisa Abdissa Baye<sup>136</sup>, Gholamreza Bazmandegan<sup>10,11</sup>, Neeraj Bedi<sup>137,138</sup>,  
 Tariku Tesfaye Tesfaye Bekuma<sup>139</sup>, Michelle L. Bell<sup>140</sup>, Isabela M. Bensenor<sup>141</sup>, Kidanemaryam Berhe<sup>142</sup>,  
 Abadi Kidanemariam Berhe<sup>143</sup>, Kidanemariam Alem Berhie<sup>144</sup>, Dinesh Bhandari<sup>145,146</sup>,  
 Nikha Bhardwaj<sup>147</sup>, Pankaj Bhardwaj<sup>148,149</sup>, Kritika Bhattacharyya<sup>150,151</sup>, Suraj Bhattarai<sup>152</sup>,  
 Zulfiqar A. Bhutta<sup>153,154</sup>, Ali Bijani<sup>155</sup>, Boris Bikbov<sup>156</sup>, Antonio Biondi<sup>157</sup>, Minyichil Birhanu<sup>158</sup>,  
 Raaj Kishore Biswas<sup>159</sup>, Moses John Bockarie<sup>160,161</sup>, Somayah Bohlouli<sup>162</sup>, Mahdi Bohluli<sup>163,164</sup>,  
 Archith Bloor<sup>165</sup>, Shiva Borzouei<sup>166</sup>, Nicola Luigi Bragazzi<sup>167</sup>, Dejana Braithwaite<sup>168,169</sup>,  
 Andre R. Brunoni<sup>141,170</sup>, Sharath Burugina Nagaraja<sup>171</sup>, Zahid A. Butt<sup>172,173</sup>,  
 Florentino Luciano Caetano dos Santos<sup>174</sup>, Luis Alberto Cámera<sup>175,176</sup>, Josip Car<sup>177,178</sup>,  
 Rosario Cárdenas<sup>179</sup>, Felix Carvalho<sup>180</sup>, Joao Mauricio Castaldelli-Maia<sup>170</sup>,  
 Carlos A. Castañeda-Orjuela<sup>181,182</sup>, Franz Castro<sup>183</sup>, Muge Cevik<sup>184,185</sup>, Wagaye Fentahun Chanie<sup>186,187</sup>,  
 Jaykaran Charan<sup>188</sup>, Souranshu Chatterjee<sup>189</sup>, Vijay Kumar Chattu<sup>190</sup>, Sarika Chaturvedi<sup>191</sup>,  
 Simiao Chen<sup>192</sup>, Ken Lee Chin<sup>193,194</sup>, Mohiuddin Ahsanul Kabir Chowdhury<sup>195,196</sup>, Aubrey J. Cook<sup>1</sup>,  
 Vera Marisa Costa<sup>180</sup>, Elizabeth A. Cromwell<sup>1,2</sup>, Berihun Assefa Dachew<sup>114,197</sup>, Henok Dagne<sup>198</sup>,  
 Baye Dagne<sup>199</sup>, Tukur Dahiru<sup>200</sup>, Saad M. A. Dahlawi<sup>201</sup>, Haijiang Dai<sup>202,203</sup>, Hancheng Dai<sup>204</sup>,  
 Lalit Dandona<sup>1,205,206</sup>, Rakhi Dandona<sup>1,2,205</sup>, Parnaz Daneshpajouhnejad<sup>207,208</sup>, Farah Daoud<sup>1</sup>,  
 Jai K. Das<sup>209</sup>, Rajat Das Gupta<sup>196,210</sup>, Aditya Prasad Dash<sup>211</sup>, Claudio Alberto Dávila-Cervantes<sup>212</sup>,  
 Kairat Davletov<sup>213</sup>, Farah Deeba<sup>214</sup>, Jan-Walter De Neve<sup>192</sup>, Edgar Denova-Gutiérrez<sup>215</sup>,  
 Kebede Deribe<sup>216,217</sup>, Assefa Desalew<sup>218</sup>, Getenet Ayalew Dessie<sup>219</sup>, Sagnik Dey<sup>220</sup>,  
 Meghnath Dhimal<sup>221</sup>, Govinda Prasad Dhungana<sup>222</sup>, Mostafa Dianatinasab<sup>223,224</sup>, Daniel Diaz<sup>225,226</sup>,  
 Isaac Oluwafemi Dipeolu<sup>227</sup>, Shirin Djalalinia<sup>228</sup>, Hoa Thi Do<sup>229</sup>, Fariba Dorostkar<sup>230</sup>,  
 Leila Doshmangir<sup>231</sup>, Bereket Duko<sup>114,232</sup>, Andre Rodrigues Duraes<sup>233,234</sup>, Lucas Earl<sup>1</sup>,  
 Hisham Atan Edinur<sup>235</sup>, Ferry Efendi<sup>236,237</sup>, Rajesh Elayedath<sup>238</sup>, Teshome Bekele Elema<sup>239,240</sup>,  
 Hala Rashad Elhabashy<sup>241</sup>, Shaimaa I. El-Jaafary<sup>14</sup>, Iman El Sayed<sup>242</sup>, Maysaa El Sayed Zaki<sup>243</sup>,

Aisha Elsharkawy<sup>244</sup>, Yasser Mohamed El-Sherbiny<sup>245,246</sup>, Maha El Tantawi<sup>247</sup>,  
 Daniel Adane Endalew<sup>248</sup>, Babak Eshtrati<sup>100</sup>, Khalil Eskandari<sup>249,250</sup>, Sharareh Eskandarieh<sup>251</sup>,  
 Ibtihal Fadhil<sup>252</sup>, Emerito Jose A. Faraon<sup>253</sup>, Mohammad Fareed<sup>254</sup>, Pawan Sirwan Faris<sup>255,256</sup>,  
 Medhat Farwati<sup>257,258</sup>, Farshad Farzadfar<sup>259</sup>, Abidemi Omolara Fasanmi<sup>260,261</sup>, Nazir Fattahi<sup>262</sup>,  
 Nelsensius Klau Fauk<sup>263,264</sup>, Valery L. Feigin<sup>1,265,266</sup>, Berhanu Elfu Feleke<sup>267</sup>,  
 Seyed-Mohammad Fereshtehnejad<sup>268,269</sup>, Eduarda Fernandes<sup>270</sup>, Pietro Ferrara<sup>271</sup>, Nataliya A. Foigt<sup>272</sup>,  
 Artem Alekseevich Fomenkov<sup>273</sup>, Masoud Foroutan<sup>274</sup>, Joel Msafiri Francis<sup>275</sup>,  
 Richard Charles Franklin<sup>276</sup>, Marisa Freitas<sup>270</sup>, Takeshi Fukumoto<sup>277</sup>, Mohamed M. Gad<sup>278,279</sup>,  
 Abhay Motiramji Gaidhane<sup>280</sup>, Reta Tsegaye Gayesa<sup>281</sup>, Biniyam Sahiledengle Geberemariam<sup>282</sup>,  
 Birhan Gebresillassie Gebregiorgis<sup>116</sup>, Hadush Gebremariam<sup>142</sup>, Tesfay B. B. Gebremariam<sup>283</sup>,  
 Leake Gebremeskel<sup>284,285</sup>, Gebreamlak Gebremedhn Gebremeskel<sup>286,287</sup>,  
 Assefa Ayalew Gebreslassie<sup>288</sup>, Yilma Chisha Dea Geramo<sup>289</sup>, Hailay Abrha Gesesew<sup>263,290</sup>,  
 Bradford D. Gessner<sup>291,292</sup>, Lemma Getacher<sup>293</sup>, Keyghobad Ghadiri<sup>294,295</sup>, Fatemeh Ghaffarifard<sup>296</sup>,  
 Mansour Ghafourifard<sup>297</sup>, Mahsa Ghajarzadeh<sup>298</sup>, Farhad Ghamari<sup>299</sup>, Ahmad Ghashghae<sup>64,300</sup>,  
 Nermin Ghith<sup>301</sup>, Syed Amir Gilani<sup>302,303</sup>, Tiffany K. Gill<sup>304</sup>, Myron Anthony Godinho<sup>305</sup>,  
 Philimon N. Gona<sup>306</sup>, Ayman Grada<sup>307</sup>, Mohammed Ibrahim Mohialdeen Gubari<sup>308</sup>, Nachiket Gudi<sup>309</sup>,  
 Davide Guido<sup>310</sup>, Rashid Abdi Guled<sup>311</sup>, Yuming Guo<sup>193,312</sup>, Rachita Gupta<sup>313</sup>, Rajeev Gupta<sup>314,315</sup>,  
 Arvin Haj-Mirzaian<sup>316,317</sup>, Randah R. Hamadeh<sup>318</sup>, Demelash Woldeyohannes Handiso<sup>319</sup>, Asif Hanif<sup>320</sup>,  
 Arief Hargono<sup>321</sup>, Ahmed I. Hasaballah<sup>322</sup>, Md Mehedi Hasan<sup>323,324</sup>, Syed Shahzad Hasan<sup>325,326</sup>,  
 Maryam Hashemian<sup>327,328</sup>, Abdiwahab Hashi<sup>329</sup>, Shoaib Hassan<sup>330,331</sup>, Amr Hassan<sup>14</sup>,  
 Soheil Hassanipour<sup>332,333</sup>, Hadi Hassankhani<sup>334,335</sup>, Khezar Hayat<sup>336,337</sup>, Mohamed I. Hegazy<sup>14</sup>,  
 Reza Heidari-Soureshjani<sup>338</sup>, Nathaniel J. Henry<sup>1,339</sup>, Claudiu Herteliu<sup>80,340</sup>, Fatemeh Heydarpour<sup>341</sup>,  
 Sousan Heydarpour<sup>341</sup>, Hagos Degefa de Hidru<sup>342</sup>, Chi Linh Hoang<sup>343</sup>, Ramesh Holla<sup>344</sup>, Julia Hon<sup>1</sup>,  
 Sung Hwi Hong<sup>345,346</sup>, Praveen Hoogar<sup>347</sup>, Seyyed Nasrollah Hosseini<sup>348</sup>, Mehdi Hosseinzadeh<sup>349,350</sup>,  
 Mihaela Hostiuc<sup>351</sup>, Sorin Hostiuc<sup>352,353</sup>, Peter J. Hotez<sup>354</sup>, Mowafa Househ<sup>355</sup>, Tanvir M. Huda<sup>195,356</sup>,  
 Dawit Hoyiso Huluko Huluko<sup>357</sup>, Syed Ather Hussain<sup>358</sup>, Bing-Fang Hwang<sup>359</sup>,  
 Olayinka Stephen Ilesanmi<sup>51,360</sup>, Irena M. Ilic<sup>361</sup>, Milena D. Ilic<sup>362</sup>, Leeberk Raja Inbaraj<sup>363</sup>,  
 Usman Iqbal<sup>364</sup>, M. Mofizul Islam<sup>365</sup>, Sheikh Mohammed Shariful Islam<sup>366,367</sup>, Chinwe Juliana Iwu<sup>34,368</sup>,  
 Chidozie C. D. Iwu<sup>369</sup>, Farhad Jadidi-Niaragh<sup>370</sup>, Mohammad Ali Jahani<sup>155</sup>, Vardhman Jain<sup>371</sup>,  
 Mihajlo Jakovljevic<sup>372,373</sup>, Amir Jalali<sup>374,375</sup>, Farzad Jalilian<sup>376</sup>, Manthan Dilipkumar Janodia<sup>377</sup>,  
 Tahereh Javaheri<sup>378</sup>, Ravi Prakash Jha<sup>379,380</sup>, Oommen John<sup>381,382</sup>, Kimberly B. Johnson<sup>1</sup>,  
 Jost B. Jonas<sup>383,384</sup>, Jitendra Jonnagaddala<sup>305,385</sup>, Nitin Joseph<sup>119</sup>, Ankur Joshi<sup>386</sup>, Farahnaz Joukar<sup>332,333</sup>,  
 Jacek Jerzy Jozwiak<sup>387</sup>, Ali Kabir<sup>388</sup>, Zubair Kabir<sup>389</sup>, Tanvir Kahlon<sup>390,391</sup>, Leila R. Kalankesh<sup>392</sup>,  
 Rohollah Kalhor<sup>393,394</sup>, Ashwin Kamath<sup>395</sup>, Zahra Kamiab<sup>11,396</sup>, Tanuj Kanchan<sup>397</sup>, Umesh Kapil<sup>398</sup>,  
 Neeti Kapoor<sup>124</sup>, Behzad Karami Matin<sup>262</sup>, Salah Eddin Karimi<sup>399</sup>, Ayele Semachew Kasa<sup>400</sup>,  
 Gebremicheal Gebreslassie Kasahun<sup>284</sup>, Zemenu Yohannes Kassa<sup>401</sup>, Gebrehiwot G. Kassa<sup>402</sup>,  
 Getinet Kassahun<sup>403</sup>, Gbenga A. Kayode<sup>404,405</sup>, Ali Kazemi Karyani<sup>262</sup>, Tibebeselassie S. Keflie<sup>406</sup>,  
 Peter Njenga Keiyoro<sup>407</sup>, Bayew Kelkay<sup>408</sup>, Maryam Keramati<sup>8</sup>, Daniel Bekele Ketema<sup>409</sup>,  
 Nauman Khalid<sup>410</sup>, Mohammad Khammarnia<sup>411</sup>, Md Nuruzzaman Khan<sup>412</sup>, Maseer Khan<sup>413</sup>,  
 Junaid Khan<sup>414</sup>, Khaled Khatab<sup>415,416</sup>, Amir M. Khater<sup>417</sup>, Mona M. Khater<sup>418</sup>, Abdullah T. Khoja<sup>419,420</sup>,  
 Jagdish Khubchandani<sup>421</sup>, Neda Kianipour<sup>422</sup>, Young-Eun Kim<sup>423</sup>, Yun Jin Kim<sup>424</sup>, Ruth W. Kimokoti<sup>425</sup>,  
 Sezer Kisa<sup>426</sup>, Adnan Kisa<sup>427,428</sup>, Tufa Kolola<sup>136</sup>, Ali Koolivand<sup>429</sup>, Soewarta Kosen<sup>430</sup>, Parvaiz A. Koul<sup>431</sup>,  
 Ai Koyanagi<sup>432,433</sup>, Kewal Krishan<sup>434</sup>, Vijay Krishnamoorthy<sup>3,435</sup>, Barthelemy Kuate Defo<sup>436,437</sup>,

Nuworza Kugbey<sup>438</sup>, Vaman Kulkarni<sup>119</sup>, G. Anil Kumar<sup>205</sup>, Nithin Kumar<sup>119</sup>, Pushpendra Kumar<sup>439</sup>,  
 Manasi Kumar<sup>440,441</sup>, Om P. Kurmi<sup>442,443</sup>, Dian Kusuma<sup>444,445</sup>, Ben Lacey<sup>446,447</sup>, Deepesh P. Lad<sup>448</sup>,  
 Dharmesh Kumar Lal<sup>205</sup>, Faris Hasan Lami<sup>449</sup>, Iván Landires<sup>450,451</sup>, Anders O. Larsson<sup>452,453</sup>,  
 Savita Lasrado<sup>454</sup>, Matthew B. Laurens<sup>455</sup>, Carlo La Vecchia<sup>456</sup>, Avula Laxmaiah<sup>457</sup>, Paul H. Lee<sup>458</sup>,  
 Shaun Wen Huey Lee<sup>459,460</sup>, Kate E. LeGrand<sup>1</sup>, Sonia Lewycka<sup>461,462</sup>, Bingyu Li<sup>463</sup>, Shanshan Li<sup>464</sup>,  
 Xuefeng Liu<sup>465</sup>, Jaifred Christian F. Lopez<sup>466,467</sup>, Daiane Borges Machado<sup>468,469</sup>,  
 Shilpashree Madhava Kunjathur<sup>470</sup>, Hassan Magdy Abd El Razek<sup>471</sup>,  
 Muhammed Magdy Abd El Razek<sup>472</sup>, D. R. Mahadeshwara Prasad<sup>473,474</sup>, Phetole Walter Mahasha<sup>475</sup>,  
 Mina Maheri<sup>476</sup>, Narayan B. Mahotra<sup>477</sup>, Azeem Majeed<sup>178</sup>, Venkatesh Maled<sup>478,479</sup>,  
 Shokofeh Maleki<sup>480</sup>, Reza Malekzadeh<sup>328,481</sup>, Deborah Carvalho Malta<sup>482</sup>, Abdullah A. Mamun<sup>323</sup>,  
 Fariborz Mansour-Ghanaei<sup>332,333</sup>, Borhan Mansouri<sup>375</sup>, Mohammad Ali Mansournia<sup>483</sup>,  
 Md Dilshad Dilshad Manzar<sup>484</sup>, Carlos Alberto Marrugo Arnedo<sup>73,485</sup>,  
 Francisco Rogerlândio Martins-Melo<sup>486</sup>, Anthony Masaka<sup>487</sup>, Pallab K. Maulik<sup>488,489</sup>,  
 Benjamin K. Mayala<sup>1,490</sup>, Medhin Mehari<sup>491</sup>, Man Mohan Mehndiratta<sup>492,493</sup>, Entezar Mehrabi Nasab<sup>494</sup>,  
 Fereshteh Mehri<sup>495</sup>, Kala M. Mehta<sup>496</sup>, Wahengbam Bigyananda Meitei<sup>497</sup>, Teferi Mekonnen<sup>498</sup>,  
 Gebrekiros Gebremichael Meles<sup>106</sup>, Mulugeta Melku<sup>499</sup>, Walter Mendoza<sup>500</sup>, Ritesh G. Menezes<sup>501</sup>,  
 Meresa Berwo Mengesha<sup>502</sup>, Endalkachew Worku Mengesha<sup>503</sup>, Tuomo J. Meretoja<sup>504,505</sup>,  
 Abera M. Mersha<sup>506</sup>, Workua Mekonnen Metekiya<sup>507</sup>, Tomasz Miazgowski<sup>508</sup>,  
 Irmina Maria Michalek<sup>509</sup>, G. K. Mini<sup>510</sup>, Shabir Ahmad Mir<sup>511</sup>, Andreea Mirica<sup>80</sup>,  
 Erkin M. Mirrakhimov<sup>512,513</sup>, Hamed Mirzaei<sup>514</sup>, Maryam Mirzaei<sup>515</sup>, Mehdi Mirzaei-Alavijeh<sup>376</sup>,  
 Sanjeev Misra<sup>516</sup>, Babak Moazen<sup>192,517</sup>, Masoud Moghadaszadeh<sup>518,519</sup>, Yousef Mohammad<sup>520</sup>,  
 Dara K. Mohammad<sup>521,522</sup>, Naser Mohammad Gholi Mezerji<sup>523</sup>, Seyyede Momeneh Mohammadi<sup>524</sup>,  
 Abdollah Mohammadian-Hafshejani<sup>525</sup>, Reza Mohammadpourhodki<sup>526</sup>, Hayat Maeruf Mohammed<sup>527</sup>,  
 Salahuddin Mohammed<sup>528,529</sup>, Ammas Siraj Mohammed<sup>530</sup>, Shafiu Mohammed<sup>192,531</sup>,  
 Jemal Abdu Mohammed<sup>532</sup>, Mohammad A. Mohseni Bandpei<sup>533</sup>, Ali H. Mokdad<sup>1,2</sup>, Alex Molassiotis<sup>458</sup>,  
 Lorenzo Monasta<sup>534</sup>, Masoud Moradi<sup>262</sup>, Maziar Moradi-Lakeh<sup>100</sup>, Rahmatollah Moradzadeh<sup>69</sup>,  
 Paula Moraga<sup>535</sup>, Abbas Mosapour<sup>536,537</sup>, Simin Mouodi<sup>155</sup>, Seyyed Meysam Mousavi<sup>538</sup>,  
 Amin Mousavi Khaneghah<sup>539</sup>, Getaneh Baye B. Mulu<sup>540</sup>, Mehnaz Munir<sup>541</sup>, Moses K. Muriithi<sup>542</sup>,  
 G. V. S. Murthy<sup>543</sup>, Ghulam Mustafa<sup>544,545</sup>, Ashraf F. Nabhan<sup>546,547</sup>, Mehdi Naderi<sup>480</sup>,  
 Ahamarshan Jayaraman Nagarajan<sup>548,549</sup>, Shankar Prasad Nagaraju<sup>550</sup>, Mohsen Naghavi<sup>1,2</sup>,  
 Gurudatta Naik<sup>551</sup>, Mukhammad David Naimzada<sup>552,553</sup>, Vinay Nangia<sup>554</sup>, Jobert Richie Nansseu<sup>555,556</sup>,  
 Atta Abbas Naqvi<sup>557,558</sup>, Bruno Ramos Nascimento<sup>559,560</sup>, Smitha Nayak<sup>561</sup>, Vinod C. Nayak<sup>127</sup>,  
 Javad Nazari<sup>562</sup>, Rawlance Ndejjo<sup>563</sup>, Ionut Negoï<sup>564,565</sup>, Ruxandra Irina Negoï<sup>566,567</sup>,  
 Henok Biresaw Netsere<sup>568,569</sup>, Georges Nguefack-Tsague<sup>556</sup>, Josephine W. Ngunjiri<sup>570</sup>,  
 Cuong Tat Nguyen<sup>571</sup>, Diep Ngoc Nguyen<sup>571,572</sup>, Huong Lan Thi Nguyen<sup>571</sup>, Yeshambel T. Nigatu<sup>573,574</sup>,  
 Rajan Nikbakhsh<sup>317</sup>, Amin Reza Nikpoor<sup>575</sup>, Chukwudi A. Nnaji<sup>368,576</sup>, Vuong Minh Nong<sup>571</sup>,  
 Jean Jacques Noubiap<sup>577</sup>, Virginia Nunez-Samudio<sup>578,579</sup>, Vincent Ebuka Nwatah<sup>580,581</sup>,  
 Tafadzwa Nyanhanda<sup>582</sup>, Bogdan Oancea<sup>583</sup>, Felix Akpojene Ogbo<sup>584</sup>, Onome Bright Oghenetega<sup>585</sup>,  
 In-Hwan Oh<sup>586</sup>, Daniel Micheal Okello<sup>587</sup>, Morteza Oladnabi<sup>588</sup>, Andrew T. Olagunju<sup>589,590</sup>,  
 Jacob Olusegun Olusanya<sup>591</sup>, Bolajoko Olubukunola Olusanya<sup>591</sup>, Ahmed Omar Bali<sup>592</sup>,  
 Muktar Omer Omer<sup>329</sup>, Abidemi E. Emmanuel Omonisi<sup>593</sup>, Obinna E. Onwujekwe<sup>594</sup>,  
 Alberto Ortiz<sup>595,596</sup>, Eduardo Ortiz-Panozo<sup>597</sup>, Nikita Otstavnov<sup>552</sup>, Stanislav S. Otstavnov<sup>552,598</sup>,  
 Mayowa O. Owolabi<sup>599,600</sup>, P. A. Mahesh<sup>601</sup>, Jagadish Rao Padubidri<sup>602</sup>, Abhijit P. Pakhare<sup>386</sup>,

Keyvan Pakshir<sup>603</sup>, Adrian Pana<sup>80,604</sup>, Songhomitra Panda-Jonas<sup>383</sup>, Anamika Pandey<sup>605</sup>, Seithikurippu R. Pandi-Perumal<sup>606</sup>, Helena Ulliyartha Pangaribuan<sup>607</sup>, Deepak Kumar Pasupula<sup>608</sup>, Sangram Kishor Patel<sup>609</sup>, Urvish K. Patel<sup>610</sup>, Ashish Pathak<sup>611,612</sup>, George C. Patton<sup>613,614</sup>, Hamidreza Pazoki Toroudi<sup>615,616</sup>, Jeevan Pereira<sup>617</sup>, Julia Moreira Pescarini<sup>468</sup>, Hai Quang Pham<sup>571</sup>, Brandon V. Pickering<sup>1</sup>, Saeed Pirouzpanah<sup>618</sup>, Meghdad Pirsaeheb<sup>262</sup>, Khem Narayan Pokhrel<sup>1619</sup>, Maarten J. Postma<sup>620,621</sup>, Faheem Hyder Pottoo<sup>622</sup>, Hadis Pourchamani<sup>623</sup>, Hadi Pourjafar<sup>624,625</sup>, Hossein Poustchi<sup>328</sup>, Sergio I. Prada<sup>626,627</sup>, Dimas Ria Angga Pribadi<sup>628</sup>, Zahiruddin Quazi Syed<sup>280</sup>, Navid Rabiee<sup>629</sup>, Ata Rafiee<sup>630</sup>, Fakher Rahim<sup>631,632</sup>, Mohammad Hifz Ur Rahman<sup>633</sup>, Muhammad Aziz Rahman<sup>237,634</sup>, Amir Masoud Rahmani<sup>349,635</sup>, Rajesh Kumar Rai<sup>636,637</sup>, Aashish Rajesh<sup>638</sup>, Pradhum Ram<sup>639</sup>, Kiana Ramezanzadeh<sup>640</sup>, Chhabi Lal Ranabhat<sup>641,642</sup>, Sowmya J. Rao<sup>643</sup>, Satish Rao<sup>644</sup>, Prateek Rastogi<sup>645</sup>, Priya Rathi<sup>344</sup>, Lal Rawal<sup>646</sup>, Wasiq Faraz Rawasia<sup>647</sup>, Reza Rawassizadeh<sup>648</sup>, Lemma Demissie Regassa<sup>187</sup>, Robert C. Reiner Jr<sup>1,2</sup>, Bhageerathy Reshmi<sup>649,650</sup>, Nima Rezaei<sup>20,651</sup>, Omid Reza Hosseini<sup>652</sup>, Aziz Rezapour<sup>64</sup>, Seyed Mohammad Riahi<sup>653</sup>, Daniela Ribeiro<sup>654</sup>, Ana Isabel Ribeiro<sup>655</sup>, Jennifer Rickard<sup>656,657</sup>, Hirbo Shore Roba<sup>187</sup>, Leonardo Roever<sup>658</sup>, Luca Ronfani<sup>534</sup>, Morteza Rostamian<sup>659</sup>, Susan Fred Rumisha<sup>660,661</sup>, Godfrey M. Rwegerera<sup>662</sup>, Siamak Sabour<sup>663</sup>, Ehsan Sadeghi<sup>262</sup>, Sahar Saedi Moghaddam<sup>259</sup>, Rajesh Sagar<sup>664</sup>, Amirhossein Sahebkar<sup>665,666</sup>, Mohammad Ali Sahraian<sup>251</sup>, S. Mohammad Sajadi<sup>667,668</sup>, Nasir Salam<sup>669</sup>, Marwa Rashad Salem<sup>670</sup>, Hossein Samadi Kafil<sup>671</sup>, Itamar S. Santos<sup>141,672</sup>, Milena M. Santric-Milicevic<sup>361,673</sup>, Sivan Yegnanarayana Iyer Saraswathy<sup>674,675</sup>, Nizal Sarrafzadegan<sup>676,677</sup>, Benn Sartorius<sup>2,678</sup>, Arash Sarveazad<sup>679</sup>, Brijesh Sathian<sup>680,681</sup>, Thirunavukkarasu Sathish<sup>682</sup>, Deepak Saxena<sup>280,683</sup>, Alyssa N. Sbarra<sup>1</sup>, David C. Schwebel<sup>684</sup>, Anbissa Muleta Senbeta<sup>685</sup>, Debarka Sengupta<sup>686</sup>, Subramanian Senthilkumaran<sup>687</sup>, Sadaf G. Sepanlou<sup>328</sup>, Allen Seylani<sup>688</sup>, Feng Sha<sup>689</sup>, Omid Shafaat<sup>690,691</sup>, Saeed Shahabi<sup>692</sup>, Mohammad Shahbaz<sup>663</sup>, Izza Shahid<sup>693</sup>, Masood Ali Shaikh<sup>694</sup>, Mohammed Feyisso Shaka<sup>695</sup>, Ali S. Shalash<sup>696</sup>, Mahdi Shamali<sup>697</sup>, Mehran Shams-Beyranvand<sup>698</sup>, Mohammad Bagher Shamsi<sup>515</sup>, Morteza Shamsizadeh<sup>699</sup>, Mohammed Shannawaz<sup>700</sup>, Kiomars Sharafi<sup>262</sup>, Amrollah Sharifi<sup>701</sup>, Aziz Sheikh<sup>702,703</sup>, Abbas Sheikhtaheri<sup>704</sup>, Ranjitha S. Shetty<sup>705</sup>, B. Suresh Kumar Shetty<sup>645</sup>, Adithi Shetty<sup>706</sup>, Wondimeneh Shibabaw Shiferaw<sup>116</sup>, Mika Shigematsu<sup>707</sup>, Jae Il Shin<sup>708</sup>, Rahman Shiri<sup>709</sup>, Reza Shirkoobi<sup>710,711</sup>, Velizar Shivarov<sup>712,713</sup>, Soraya Siabani<sup>714,715</sup>, Sudeep K. Siddappa Malleshappa<sup>716</sup>, Tariq Jamal Siddiqi<sup>717</sup>, Negussie Boti Sidemo<sup>289</sup>, Balbir Bagicha Singh<sup>718,719</sup>, Surya Singh<sup>720</sup>, Yitagesu Sintayehu<sup>721</sup>, Valentin Yurievich Skryabin<sup>722</sup>, Anna Aleksandrovna Skryabina<sup>723</sup>, Mohammad Reza Sobhiyeh<sup>724</sup>, Amin Soheili<sup>725</sup>, Shahin Soltani<sup>262</sup>, Muluken Bekele Sorrie<sup>289</sup>, Emma Elizabeth Spurlock<sup>1</sup>, Chandrashekhar T. Sreeramareddy<sup>726</sup>, Agus Sudaryanto<sup>727</sup>, Mu'awiyah Babale Sufiyan<sup>200</sup>, Iyad Sultan<sup>728,729</sup>, Rafael Tabarés-Seisdedos<sup>730,731</sup>, Takahiro Tabuchi<sup>732</sup>, Biruk Wogayehu Taddele<sup>733</sup>, Eyayou Girma Tadesse<sup>734</sup>, Amir Taherkhani<sup>735</sup>, Zemenu Tamir<sup>736</sup>, Animut Tagele Tamiru<sup>408</sup>, Md Ismail Tareque<sup>737</sup>, Abdelghani Tbakhi<sup>738</sup>, Hirut Teame<sup>342</sup>, Yonas Getaye Tefera<sup>739</sup>, Arash Tehrani-Banihashemi<sup>100,740</sup>, Yohannes Tekalegn<sup>282</sup>, Merhawi Gebremedhin Tekle<sup>187</sup>, Berhane Fseha Teklehaimanot<sup>342</sup>, Mohamad-Hani Temsah<sup>741</sup>, Getayeneh Antehunegn Tesema<sup>129</sup>, Kavumpurathu Raman Thankappan<sup>742</sup>, Nihal Thomas<sup>743</sup>, Takele Tiki<sup>744</sup>, Asres Bedaso Tilahun<sup>357</sup>, Mariya Vladimirovna Titova<sup>552,745</sup>, Marcos Roberto Tovani-Palone<sup>746,747</sup>, Khanh Bao Tran<sup>748,749</sup>, Bach Xuan Tran<sup>750</sup>, Rajnish Tripathi<sup>751</sup>, Jaya Prasad Tripathy<sup>752</sup>, Phuong N. Truong<sup>753</sup>, Riaz Uddin<sup>366,754</sup>, Anayat Ullah<sup>755</sup>, Chukwuma David Umeokonkwo<sup>756</sup>, Chigozie Jesse Uneke<sup>757</sup>, Bhaskaran Unnikrishnan<sup>758</sup>,

Era Upadhyay<sup>759</sup>, Muhammad Shariq Usman<sup>760</sup>, Marco Vacante<sup>157</sup>, Alireza Vakilian<sup>761,762</sup>, Sahel Valadan Tahbaz<sup>763,764</sup>, Pascual R. Valdez<sup>765,766</sup>, Yasser Vasseghian<sup>349</sup>, Madhur Verma<sup>767</sup>, Francesco S. Violante<sup>768,769</sup>, Bay Vo<sup>770</sup>, Yohannes Dibaba Wado<sup>771</sup>, Yasir Waheed<sup>772</sup>, Yafeng Wang<sup>773</sup>, Yuan-Pang Wang<sup>170</sup>, Kinley Wangdi<sup>774</sup>, Girmay Teklay Weldesamuel<sup>286</sup>, Andrea Werdecker<sup>775</sup>, Taweewat Wiangkham<sup>776</sup>, Nuwan Darshana Wickramasinghe<sup>777</sup>, Charles Shey Wiysonge<sup>368,576</sup>, Tewodros Eshete Wonde<sup>409</sup>, Ai-Min Wu<sup>778</sup>, Chenkai Wu<sup>779,780</sup>, Yang Xie<sup>781</sup>, Ali Yadollahpour<sup>782</sup>, Seyed Hossein Yahyazadeh Jabbari<sup>763</sup>, Tomohide Yamada<sup>783</sup>, Mingyou Yang<sup>1</sup>, Sanni Yaya<sup>784,785</sup>, Vahid Yazdi-Feyzabadi<sup>786,787</sup>, Tomas Y. Yeheyis<sup>357</sup>, Alex Yeshaneh<sup>248</sup>, Yigizie Yeshaw<sup>129</sup>, Yordanos Gizachew Yeshitila<sup>506</sup>, Mekdes Tigistu Yilma<sup>139</sup>, Paul Yip<sup>788,789</sup>, Melissa F. Young<sup>790</sup>, Zabihollah Yousefi<sup>791</sup>, Taraneh Yousefinezhadi<sup>792</sup>, Hebat-Allah Salah A. Yousof<sup>418</sup>, Abdilahi Yousuf Yousuf<sup>329</sup>, Chuanhua Yu<sup>773</sup>, Yong Yu<sup>793</sup>, Shamsa Zafar<sup>794,795</sup>, Syed Saoud Zaidi<sup>796</sup>, Zoubida Zaidi<sup>797</sup>, Josefina Zakzuk<sup>798</sup>, Sojib Bin Zaman<sup>195,799</sup>, Mohammad Zamani<sup>800</sup>, Maryam Zamanian<sup>69</sup>, Alireza Zandifar<sup>801</sup>, Alireza Zangeneh<sup>376</sup>, Mikhail Sergeevich Zastrozhin<sup>802,803</sup>, Anasthasia Zastrozhina<sup>804</sup>, Dejene Tesfaye Zewdie<sup>805</sup>, Kaleab Alemayehu Zewdie<sup>806</sup>, Yunquan Zhang<sup>807,808</sup>, Cong Zhu<sup>809</sup> and Arash Ziapour<sup>714</sup>

<sup>5</sup>Global Programs, Medical Teams International, Seattle, WA, USA. <sup>6</sup>Department of Pediatric Newborn Medicine, Brigham and Women's Hospital, Boston, MA, USA. <sup>7</sup>Maternal and Child Wellbeing, African Population and Health Research Center, Nairobi, Kenya. <sup>8</sup>Mashhad University of Medical Sciences, Mashhad, Iran. <sup>9</sup>Montreal Neurological Institute, McGill University, Montreal, QC, Canada. <sup>10</sup>Department of Internal Medicine, Rafsanjan University of Medical Sciences, Rafsanjan, Iran. <sup>11</sup>Clinical Research Development Unit, Rafsanjan University of Medical Sciences, Rafsanjan, Iran. <sup>12</sup>Social Determinants of Health Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran. <sup>13</sup>Advanced Diagnostic and Interventional Radiology Research Center, Tehran University of Medical Sciences, Tehran, Iran. <sup>14</sup>Department of Neurology, Cairo University, Cairo, Egypt. <sup>15</sup>Tropical Medicine Department, Tanta University, Tanta, Egypt. <sup>16</sup>Department of Parasitology and Mycology, Jahrom University of Medical Sciences, Jahrom, Iran. <sup>17</sup>Neuroscience Research Center, Isfahan University of Medical Sciences, Isfahan, Iran. <sup>18</sup>Department of Orthopaedic Surgery, University of Southern California, Los Angeles, CA, USA. <sup>19</sup>Department of Laboratory Medicine, Karolinska University Hospital, Huddinge, Sweden. <sup>20</sup>Research Center for Immunodeficiencies, Tehran University of Medical Sciences, Tehran, Iran. <sup>21</sup>Department of Economics, NMSM Government College, Kalpetta, India. <sup>22</sup>Department of Pediatric Dentistry, Federal University of Minas Gerais, Belo Horizonte, Brazil. <sup>23</sup>Department of Research, Philippine Institute for Development Studies, Quezon City, Philippines. <sup>24</sup>Department of Clinical Sciences, University of Sharjah, Sharjah, United Arab Emirates. <sup>25</sup>Harvard Medical School, Harvard University, Boston, MA, USA. <sup>26</sup>Department of Medicine, Ain Shams University, Cairo, Egypt. <sup>27</sup>Department of Disease Control, London School of Hygiene & Tropical Medicine, London, UK. <sup>28</sup>Clinical Research and Operations, Foundation for Scientific Research (FORS), Cotonou, Benin. <sup>29</sup>Hamadan University of Medical Sciences, Hamadan, Iran. <sup>30</sup>College of Medicine, University College Hospital, Ibadan, Ibadan, Nigeria. <sup>31</sup>School of Medicine, Griffith University, Gold Coast, QLD, Australia. <sup>32</sup>Population Health Sciences, King's College London, London, UK. <sup>33</sup>Centre of Excellence for Epidemiological Modelling and Analysis, Stellenbosch University, Stellenbosch, South Africa. <sup>34</sup>Department of Global Health, Stellenbosch University, Cape Town, South Africa. <sup>35</sup>Department of Community Health and Epidemiology, University of Saskatchewan, Saskatoon, SK, Canada. <sup>36</sup>Department of Public Health, Federal Ministry of Health, Abuja, Nigeria. <sup>37</sup>School of Health, Ardabil University of Medical Science, Ardabil, Iran. <sup>38</sup>Social Behavioral Research Branch, National Institute of Health, Bethesda, MD, USA. <sup>39</sup>Department of Oncology, Georgetown University, Washington DC, USA. <sup>40</sup>Department of Cardiovascular Medicine, Mayo Clinic, Scottsdale, AZ, USA. <sup>41</sup>Department of Epidemiology and Biostatistics, Qom University of Medical Sciences, Qom, Iran. <sup>42</sup>Faculty of Pharmacy, MAHSA University, Kuala Langat, Malaysia. <sup>43</sup>Department of Epidemiology and Health Statistics, Southeast University, Nanjing, China. <sup>44</sup>Lincoln Medical School, Universities of Nottingham & Lincoln, Lincoln, UK. <sup>45</sup>School of Advanced Technologies in Medicine, Shahid Beheshti University of Medical Sciences, Tehran, Iran. <sup>46</sup>Department of Epidemiology, Jimma University, Jimma, Ethiopia. <sup>47</sup>Australian Center for Precision Health, University of South Australia, Adelaide, SA, Australia. <sup>48</sup>Higher National School of Veterinary Medicine, Algiers, Algeria. <sup>49</sup>Faculty of Medicine and Public Health, Jenderal Soedirman University, Purwokerto, Indonesia. <sup>50</sup>Department of Health Policy and Management, University of Ibadan, Ibadan, Nigeria. <sup>51</sup>Department of Community Medicine, University College Hospital, Ibadan, Ibadan, Nigeria. <sup>52</sup>Department of Medical Laboratory Sciences, Arba Minch University, Arba Minch, Ethiopia. <sup>53</sup>Department of Public Health, The Intercountry Centre for Oral Health (ICOH) for Africa, Jos, Nigeria. <sup>54</sup>Department of Public Health, Federal Ministry of Health, Garki, Nigeria. <sup>55</sup>John T. Milliken Department of Internal Medicine, Washington University in St. Louis, St. Louis, MO, USA. <sup>56</sup>Clinical Epidemiology Center, Department of Veterans Affairs, St. Louis, MO, USA. <sup>57</sup>Health Information Management and Technology Department, Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia. <sup>58</sup>Center for Health System Research, National Institute of Public Health, Cuernavaca, Mexico. <sup>59</sup>College of Medicine and Health Science, Arba Minch University, Arba Minch, Ethiopia. <sup>60</sup>Department of Midwifery, Arba Minch University, Injbara, Ethiopia. <sup>61</sup>HIV and TB Research Directorate, Ethiopian Public Health Institute, Addis Ababa, Ethiopia. <sup>62</sup>Institute of Health Research, University of Health and Allied Sciences, Ho, Ghana. <sup>63</sup>Epidemiology and Preventive Medicine, Monash University, Melbourne, VIC, Australia. <sup>64</sup>Health Management and Economics Research Center, Iran University of Medical Sciences, Tehran, Iran. <sup>65</sup>Health Economics Department, Iran University of Medical Sciences, Tehran, Iran. <sup>66</sup>Infectious and Tropical Disease Research Center, Hormozgan University of Medical Sciences, Bandar Abbas, Iran. <sup>67</sup>Department of Health Policy and Management, Kuwait University, Safat, Kuwait. <sup>68</sup>International Centre for Casemix and Clinical Coding, National University of Malaysia, Bandar Tun Razak, Malaysia. <sup>69</sup>Department of Epidemiology, Arak University of Medical Sciences, Arak, Iran. <sup>70</sup>Medical Research Center, Jazan University, Jazan, Saudi Arabia. <sup>71</sup>Department of Parasitology, Sana'a University, Sana'a, Yemen. <sup>72</sup>Department of Community Medicine, King Abdulaziz University, Jeddah, Saudi Arabia. <sup>73</sup>Research Group in Health Economics, University of Cartagena, Cartagena, Colombia. <sup>74</sup>Research Group in Hospital Management and Health Policies, ALZAK Foundation, Cartagena, Colombia. <sup>75</sup>Health Services Management Department, Arak University of Medical Sciences, Arak, Iran. <sup>76</sup>Department of Radiology and Nuclear Medicine, Kermanshah University of Medical Sciences, Kermanshah, Iran. <sup>77</sup>Mansoura University, Mansoura, Egypt. <sup>78</sup>Faculty of Medicine, Mansoura University, Mansoura, Egypt. <sup>79</sup>Pharmacy Department, Carol Davila University of Medicine and Pharmacy, Bucharest, Romania. <sup>80</sup>Department of Statistics and Econometrics, Bucharest University of Economic Studies, Bucharest, Romania. <sup>81</sup>Division of Human

Nutrition and Health, Wageningen University & Research, Wageningen, Netherlands. <sup>82</sup>Nutrition & Food Science Research Directorate, Ethiopian Public Health Institute, Addis Ababa, Ethiopia. <sup>83</sup>Social Determinants of Health Research Center, Rafsanjan University of Medical Sciences, Rafsanjan, Iran. <sup>84</sup>Research Center for Evidence Based Medicine, Tabriz University of Medical Sciences, Tabriz, Iran. <sup>85</sup>Razi Vaccine and Serum Research Institute, Agricultural Research, Education, and Extension Organization (AREEO), Tehran, Iran. <sup>86</sup>Department of Epidemiology and Biostatistics, Zahedan University of Medical Sciences, Zahedan, Iran. <sup>87</sup>Department of Epidemiology, Bahir Dar University, Bahir Dar, Ethiopia. <sup>88</sup>Agribusines Study Program, Sebelas Maret University, Surakarta, Indonesia. <sup>89</sup>Department of Parasitology, Mazandaran University of Medical Sciences, Sari, Iran. <sup>90</sup>Department of Parasitology, Iranshahr University of Medical Sciences, Iranshahr, Iran. <sup>91</sup>Department of Pathology, Imam Mohammad Ibn Saud Islamic University, Riyadh, Saudi Arabia. <sup>92</sup>Department of Psychology, Foundation University Islamabad, Rawalpindi, Pakistan. <sup>93</sup>Social Determinants of Health Research Center, Birjand University of Medical Sciences, Birjand, Iran. <sup>94</sup>Department of Public Health, Birmingham City University, Birmingham, UK. <sup>95</sup>School of Nursing and Midwifery, Addis Ababa University, Addis Ababa, Ethiopia. <sup>96</sup>Independent Consultant, Windsor, MB, Canada. <sup>97</sup>School of Nursing and Midwifery, Babol University of Medical Sciences, Babol, Iran. <sup>98</sup>Babol University of Medical Sciences, Babol, Iran. <sup>99</sup>Department of Plastic Surgery, The University of Texas Health Science Center at Houston, Houston, TX, USA. <sup>100</sup>Preventive Medicine and Public Health Research Center, Iran University of Medical Sciences, Tehran, Iran. <sup>101</sup>Epilepsy Research Center, Shiraz University of Medical Sciences, Shiraz, Iran. <sup>102</sup>Department of Neurology, Thomas Jefferson University, Philadelphia, PA, USA. <sup>103</sup>School of Public Health, Bahir Dar University, Bahir Dar, Ethiopia. <sup>104</sup>Department of Biostatistics and Epidemiology, Tabriz University of Medical Sciences, Tabriz, Iran. <sup>105</sup>Department of Biostatistics and Epidemiology, Zanjan University of Medical Sciences, Zanjan, Iran. <sup>106</sup>School of Public Health, Mekelle University, Mekelle, Ethiopia. <sup>107</sup>Department of Medical Laboratory Science, Haramaya University, Harar, Ethiopia. <sup>108</sup>Department of Biology, Maragheh University of Medical Sciences, Maragheh, Iran. <sup>109</sup>Department of Immunology, Zanjan University of Medical Sciences, Zanjan, Iran. <sup>110</sup>Faculty of Nursing, Philadelphia University, Amman, Jordan. <sup>111</sup>School of Business, University of Leicester, Leicester, UK. <sup>112</sup>Department of Nursing, Wolaita Sodo University, Wolaita Sodo, Ethiopia. <sup>113</sup>The Judith Lumley Centre, La Trobe University, Melbourne, VIC, Australia. <sup>114</sup>School of Public Health, Curtin University, Perth, WA, Australia. <sup>115</sup>Department of Health Policy Planning and Management, University of Health and Allied Sciences, Ho, Ghana. <sup>116</sup>Department of Nursing, Debre Berhan University, Debre Berhan, Ethiopia. <sup>117</sup>Department of Pharmacology and Toxicology, Mekelle University, Mekelle, Ethiopia. <sup>118</sup>Cellular and Molecular Biology Research Center, Babol University of Medical Sciences, Babol, Iran. <sup>119</sup>Department of Community Medicine, Manipal Academy of Higher Education, Mangalore, India. <sup>120</sup>Department of Public Health Medicine, University of KwaZulu-Natal, Durban, South Africa. <sup>121</sup>Department of Community Health and Primary Care, University of Lagos, Lagos, Nigeria. <sup>122</sup>Public Health Risk Sciences Division, Public Health Agency of Canada, Toronto, ON, Canada. <sup>123</sup>Department of Nutritional Sciences, University of Toronto, Toronto, ON, Canada. <sup>124</sup>Department of Forensic Science, Government Institute of Forensic Science, Nagpur, India. <sup>125</sup>Department of Healthcare Management and Education, Shiraz University of Medical Sciences, Shiraz, Iran. <sup>126</sup>Centre for Community Medicine, All India Institute of Medical Sciences, New Delhi, India. <sup>127</sup>Department of Forensic Medicine and Toxicology, Manipal Academy of Higher Education, Manipal, India. <sup>128</sup>Department of Non-communicable Diseases, Bangladesh University of Health Sciences, Dhaka, Bangladesh. <sup>129</sup>Department of Epidemiology and Biostatistics, University of Gondar, Gondar, Ethiopia. <sup>130</sup>Department of Neurosciences, Costa Rican Department of Social Security, San Jose, Costa Rica. <sup>131</sup>School of Medicine, University of Costa Rica, San Pedro, Costa Rica. <sup>132</sup>School of Public Health and Community Medicine, Aden College, Aden, Yemen. <sup>133</sup>Center for Primary Care, Harvard University, Boston, MA, USA. <sup>134</sup>School of Public Health, Imperial College London, London, UK. <sup>135</sup>Health Human Resources Research Center, Shiraz University of Medical Sciences, Shiraz, Iran. <sup>136</sup>Department of Public Health, Ambo University, Ambo, Ethiopia. <sup>137</sup>Department of Community Medicine, Gandhi Medical College Bhopal, Bhopal, India. <sup>138</sup>Jazan University, Jazan, Saudi Arabia. <sup>139</sup>Department of Public Health, Wollega University, Nekemte, Ethiopia. <sup>140</sup>School of the Environment, Yale University, New Haven, CT, USA. <sup>141</sup>Department of Internal Medicine, University of São Paulo, São Paulo, Brazil. <sup>142</sup>Department of Nutrition and Dietetics, Mekelle University, Mekelle, Ethiopia. <sup>143</sup>College of Medicine and Health Sciences, Adigrat University, Adigrat, Ethiopia. <sup>144</sup>Department of Biostatistics, Mekelle University, Mekelle, Ethiopia. <sup>145</sup>School of Public Health, University of Adelaide, Adelaide, SA, Australia. <sup>146</sup>Public Health Research Laboratory, Tribhuvan University, Kathmandu, Nepal. <sup>147</sup>Department of Anatomy, Government Medical College Pali, Pali, India. <sup>148</sup>Department of Community Medicine and Family Medicine, All India Institute of Medical Sciences, Jodhpur, India. <sup>149</sup>School of Public Health, All India Institute of Medical Sciences, Jodhpur, India. <sup>150</sup>Department of Statistical and Computational Genomics, National Institute of Biomedical Genomics, Kalyani, India. <sup>151</sup>Department of Statistics, University of Calcutta, Kolkata, India. <sup>152</sup>Department of Global Health, Global Institute for Interdisciplinary Studies, Kathmandu, Nepal. <sup>153</sup>Centre for Global Child Health, University of Toronto, Toronto, ON, Canada. <sup>154</sup>Centre of Excellence in Women & Child Health, Aga Khan University, Karachi, Pakistan. <sup>155</sup>Social Determinants of Health Research Center, Babol University of Medical Sciences, Babol, Iran. <sup>156</sup>Mario Negri Institute for Pharmacological Research, Ranica, Italy. <sup>157</sup>Department of General Surgery and Medical-Surgical Specialties, University of Catania, Catania, Italy. <sup>158</sup>Department of Pediatrics and Child Health Nursing, Bahir Dar University, Bahir Dar, Ethiopia. <sup>159</sup>Transport and Road Safety (TARS) Research Centre, University of New South Wales, Sydney, NSW, Australia. <sup>160</sup>European & Developing Countries Clinical Trials Partnership, Cape Town, South Africa. <sup>161</sup>Department of Medicine, University of Cape Town, Cape Town, South Africa. <sup>162</sup>Department of Veterinary Medicine, Islamic Azad University, Kermanshah, Iran. <sup>163</sup>Department of Computer Science and Information Technology, Institute for Advanced Studies in Basic Sciences, Zanjan, Iran. <sup>164</sup>Department of Research and Innovation, Petanux Research GmbH, Bonn, Germany. <sup>165</sup>Department of Internal Medicine, Manipal Academy of Higher Education, Mangalore, India. <sup>166</sup>Department of Endocrinology, Hamadan University of Medical Sciences, Hamadan, Iran. <sup>167</sup>University of Genoa, Genoa, Italy. <sup>168</sup>Department of Epidemiology, University of Florida, Gainesville, FL, USA. <sup>169</sup>Cancer Population Sciences Program, University of Florida Health Cancer Center, Gainesville, FL, USA. <sup>170</sup>Department of Psychiatry, University of São Paulo, São Paulo, Brazil. <sup>171</sup>Department of Community Medicine, Employee State Insurance Post Graduate Institute of Medical Sciences and Research, Bangalore, India. <sup>172</sup>School of Public Health and Health Systems, University of Waterloo, Waterloo, ON, Canada. <sup>173</sup>Al Shifa School of Public Health, Al Shifa Trust Eye Hospital, Rawalpindi, Pakistan. <sup>174</sup>Institute of Microengineering, Federal Polytechnic School of Lausanne, Lausanne, Switzerland. <sup>175</sup>Internal Medicine Department, Italian Hospital of Buenos Aires (Hospital Italiano de Buenos Aires), Buenos Aires, Argentina. <sup>176</sup>Board of Directors, Argentine Society of Medicine, Buenos Aires, Argentina. <sup>177</sup>Centre for Population Health Sciences, Nanyang Technological University, Singapore, Singapore. <sup>178</sup>Department of Primary Care and Public Health, Imperial College London, London, UK. <sup>179</sup>Department of Health Care, Metropolitan Autonomous University, Mexico City, Mexico. <sup>180</sup>Research Unit on Applied Molecular Biosciences (UCIBIO), University of Porto, Porto, Portugal. <sup>181</sup>Colombian National Health Observatory, National Institute of Health, Bogota, Colombia. <sup>182</sup>Epidemiology and Public Health Evaluation Group, National University of Colombia, Bogota, Colombia. <sup>183</sup>Gorgas Memorial Institute for Health Studies, Panama City, Panama. <sup>184</sup>Infection and Global Health Research, University of St. Andrews, St. Andrews, UK. <sup>185</sup>Regional Infectious Diseases Unit, NHS National Services Scotland, Edinburgh, UK. <sup>186</sup>Institute of Public Health, University of Gondar, Gondar, Ethiopia. <sup>187</sup>School of Public Health, Haramaya University, Harar, Ethiopia. <sup>188</sup>Department of Pharmacology, All India Institute of Medical Sciences, Jodhpur, India. <sup>189</sup>Department of Microbiology & Infection Control, Medanta Medicity, Gurugram, India. <sup>190</sup>Department of Medicine, University of Toronto, Toronto, ON, Canada. <sup>191</sup>Research Department, D. Y. Patil University, Pune, India. <sup>192</sup>Heidelberg Institute of Global Health (HIGH), Heidelberg University, Heidelberg, Germany. <sup>193</sup>Department of Epidemiology and Preventive Medicine, Monash University, Melbourne, VIC, Australia. <sup>194</sup>Melbourne Medical School, University of Melbourne, Parkville, VIC, Australia. <sup>195</sup>Maternal and Child Health Division, International Centre for Diarrhoeal Disease Research, Bangladesh, Dhaka, Bangladesh. <sup>196</sup>Department of Epidemiology and Biostatistics, University of South Carolina, Columbia, SC, USA. <sup>197</sup>Department of Epidemiology, University of Gondar, Gondar, Ethiopia. <sup>198</sup>Department of Environmental Health and Occupational Health and Safety, University of Gondar, Gondar, Ethiopia. <sup>199</sup>Department of Human Physiology, University of Gondar, Gondar, Ethiopia. <sup>200</sup>Department of Community Medicine, Ahmadu Bello University,



Zaria, Nigeria. <sup>201</sup>Environmental Health Department, Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia. <sup>202</sup>Department of Cardiology, Central South University, Changsha, China. <sup>203</sup>Department of Mathematics and Statistics, York University, Toronto, ON, Canada. <sup>204</sup>College of Environmental Sciences and Engineering, Peking University, Beijing, China. <sup>205</sup>Public Health Foundation of India, Gurugram, India. <sup>206</sup>Indian Council of Medical Research, New Delhi, India. <sup>207</sup>Department of Pathology, Johns Hopkins University School of Medicine, Baltimore, MD, USA. <sup>208</sup>Department of Pathology, Isfahan University of Medical Sciences, Isfahan, Iran. <sup>209</sup>Division of Women and Child Health, Aga Khan University, Karachi, Pakistan. <sup>210</sup>James P Grant School of Public Health, BRAC University, Dhaka, Bangladesh. <sup>211</sup>Asian Institute of Public Health University, Bhubaneswar, India. <sup>212</sup>Department of Population and Development, Latin American Faculty of Social Sciences Mexico, Mexico City, Mexico. <sup>213</sup>Health Research Institute, Al Farabi Kazakh National University, Almaty, Kazakhstan. <sup>214</sup>Centre for Interdisciplinary Research in Basic Sciences, Jamia Millia Islamia, Delhi, India. <sup>215</sup>Center for Nutrition and Health Research, National Institute of Public Health, Cuernavaca, Mexico. <sup>216</sup>Wellcome Trust Brighton and Sussex Centre for Global Health Research, Brighton and Sussex Medical School, Brighton, UK. <sup>217</sup>School of Public Health, Addis Ababa University, Addis Ababa, Ethiopia. <sup>218</sup>School of Nursing and Midwifery, Haramaya University, Harar, Ethiopia. <sup>219</sup>Department of Nursing, Bahir Dar University, Bahir Dar, Ethiopia. <sup>220</sup>Centre for Atmospheric Sciences, Indian Institute of Technology Delhi, New Delhi, India. <sup>221</sup>Health Research Section, Nepal Health Research Council, Kathmandu, Nepal. <sup>222</sup>Department of Microbiology, Far Western University, Mahendranagar, Nepal. <sup>223</sup>Department of Epidemiology and Biostatistics, Shahroud University of Medical Sciences, Shahroud, Iran. <sup>224</sup>Department of Epidemiology, Shiraz University of Medical Sciences, Shiraz, Iran. <sup>225</sup>Center of Complexity Sciences, National Autonomous University of Mexico, Mexico City, Mexico. <sup>226</sup>Faculty of Veterinary Medicine and Zootechnics, Autonomous University of Sinaloa, Culiacán Rosales, Mexico. <sup>227</sup>Department of Health Promotion and Education, University of Ibadan, Ibadan, Nigeria. <sup>228</sup>Development of Research and Technology Center, Ministry of Health and Medical Education, Tehran, Iran. <sup>229</sup>Institute of Health Economics and Technology, Hanoi, Vietnam. <sup>230</sup>Department of Medical Laboratory Sciences, Faculty of Allied Medicine, Tehran, Iran. <sup>231</sup>Department of Health Policy and Management, Tabriz University of Medical Sciences, Tabriz, Iran. <sup>232</sup>School of Public Health, Hawassa University, Hawassa, Ethiopia. <sup>233</sup>School of Medicine, Federal University of Bahia, Salvador, Brazil. <sup>234</sup>Department of Internal Medicine, Bahiana School of Medicine and Public Health (Escola Bahiana de Medicina e Saúde Pública), Salvador, Brazil. <sup>235</sup>School of Health Sciences, University of Science Malaysia (Universiti Sains Malaysia), Kubang Kerian, Kelantan, Malaysia. <sup>236</sup>Department of Community Health Nursing, Airlangga University (Universitas Airlangga), Surabaya, Indonesia. <sup>237</sup>School of Nursing and Midwifery, La Trobe University, Melbourne, VIC, Australia. <sup>238</sup>School of Behavioural Sciences, Mahatma Gandhi University of Medical Sciences and Technology, Kottayam, India. <sup>239</sup>Department of Food Science and Nutrition, Arsi University, Asella, Ethiopia. <sup>240</sup>Center for Food Science and Nutrition, Addis Ababa University, Addis Ababa, Ethiopia. <sup>241</sup>Neurophysiology Department, Cairo University, Cairo, Egypt. <sup>242</sup>Biomedical Informatics and Medical Statistics Department, Alexandria University, Alexandria, Egypt. <sup>243</sup>Reference Laboratory of Egyptian Universities Hospitals, Ministry of Higher Education and Research, Cairo, Egypt. <sup>244</sup>Endemic Medicine and Hepatogastroenterology Department, Cairo University, Cairo, Egypt. <sup>245</sup>Department of Biosciences, Nottingham Trent University, Nottingham, UK. <sup>246</sup>Clinical Pathology Department, Mansoura University, Mansoura, Egypt. <sup>247</sup>Pediatric Dentistry and Dental Public Health Department, Alexandria University, Alexandria, Egypt. <sup>248</sup>Department of Midwifery, Wolkite University, Wolkite, Ethiopia. <sup>249</sup>Department of Medicinal Chemistry, Kerman University of Medical Sciences, Kerman, Iran. <sup>250</sup>Pharmaceutics Research Center, Kerman University of Medical Sciences, Kerman, Iran. <sup>251</sup>Multiple Sclerosis Research Center, Tehran University of Medical Sciences, Tehran, Iran. <sup>252</sup>Division of Non-Communicable Diseases, Ministry of Public Health and Population, Dubai, United Arab Emirates. <sup>253</sup>Department of Health Policy and Administration, University of the Philippines Manila, Manila, Philippines. <sup>254</sup>College of Medicine, Imam Mohammad Ibn Saud Islamic University, Riyadh, Saudi Arabia. <sup>255</sup>Department of Biology and Biotechnology 'Lazzaro Spallanzani', University of Pavia, Pavia, Italy. <sup>256</sup>Department of Biology, Cihan University-Erbil, Erbil, Iraq. <sup>257</sup>Internal Medicine Department, Cleveland Clinic, Cleveland, OH, USA. <sup>258</sup>Department of Cardiovascular Medicine, Mayo Clinic, Rochester, MN, USA. <sup>259</sup>Non-communicable Diseases Research Center, Tehran University of Medical Sciences, Tehran, Iran. <sup>260</sup>Satcher Health Leadership Institute, Morehouse School of Medicine, Atlanta, GA, USA. <sup>261</sup>School of Medicine, Emory University, Atlanta, GA, USA. <sup>262</sup>Research Center for Environmental Determinants of Health, Kermanshah University of Medical Sciences, Kermanshah, Iran. <sup>263</sup>College of Medicine and Public Health, Flinders University, Adelaide, SA, Australia. <sup>264</sup>Institute of Resource Governance and Social Change, Kupang, Indonesia. <sup>265</sup>National Institute for Stroke and Applied Neurosciences, Auckland University of Technology, Auckland, New Zealand. <sup>266</sup>Research Center of Neurology, Moscow, Russia. <sup>267</sup>Department of Epidemiology and Biostatistics, Bahir Dar University, Bahir Dar, Ethiopia. <sup>268</sup>Department of Neurobiology, Karolinska Institute, Stockholm, Sweden. <sup>269</sup>Division of Neurology, University of Ottawa, Ottawa, ON, Canada. <sup>270</sup>Associated Laboratory for Green Chemistry (LAQV), University of Porto, Porto, Portugal. <sup>271</sup>Research Center on Public Health, University of Milan Bicocca, Monza, Italy. <sup>272</sup>Institute of Gerontology, National Academy of Medical Sciences of Ukraine, Kyiv, Ukraine. <sup>273</sup>Department of Cell Biology and Biotechnology, K.A. Timiryazev Institute of Plant Physiology, Moscow, Russia. <sup>274</sup>Department of Medical Parasitology, Abadan Faculty of Medical Sciences, Abadan, Iran. <sup>275</sup>Department of Family Medicine and Primary Care, University of the Witwatersrand, Johannesburg, South Africa. <sup>276</sup>School of Public Health, Medical, and Veterinary Sciences, James Cook University, Douglas, QLD, Australia. <sup>277</sup>Department of Dermatology, Kobe University, Kobe, Japan. <sup>278</sup>Department of Cardiovascular Medicine, Cleveland Clinic, Cleveland, OH, USA. <sup>279</sup>Gillings School of Global Public Health, University of North Carolina Chapel Hill, Chapel Hill, NC, USA. <sup>280</sup>Department of Community Medicine, Datta Meghe Institute of Medical Sciences, Wardha, India. <sup>281</sup>Department of Nursing, Wollega University, Nekemte, Ethiopia. <sup>282</sup>Department of Public Health, Madda Walabu University, Bale Robe, Ethiopia. <sup>283</sup>Department of Human Nutrition, Aksum University, Mekelle, Ethiopia. <sup>284</sup>School of Pharmacy, Aksum University, Aksum, Ethiopia. <sup>285</sup>Department of Pharmacy, Mekelle University, Mekelle, Ethiopia. <sup>286</sup>Department of Nursing, Aksum University, Aksum, Ethiopia. <sup>287</sup>Department of Nursing, Mekelle University, Mekelle, Ethiopia. <sup>288</sup>Department of Reproductive Health, Mekelle University, Mekelle, Ethiopia. <sup>289</sup>Department of Public Health, Arba Minch University, Arba Minch, Ethiopia. <sup>290</sup>Department of Epidemiology, Mekelle University, Mekelle, Ethiopia. <sup>291</sup>Pfizer Vaccines, Collegeville, PA, USA. <sup>292</sup>Agency of Preventive Medicine, Paris, France. <sup>293</sup>Department of Public Health, Debre Berhan University, Debre Berhan, Ethiopia. <sup>294</sup>Infectious Disease Research Center, Kermanshah University of Medical Sciences, Kermanshah, Iran. <sup>295</sup>Pediatric Department, Kermanshah University of Medical Sciences, Kermanshah, Iran. <sup>296</sup>Department of Parasitology and Entomology, Tarbiat Modares University, Tehran, Iran. <sup>297</sup>Department of Medical Surgical Nursing, Tabriz University of Medical Sciences, Tabriz, Iran. <sup>298</sup>Department of Neurology, Tehran University of Medical Sciences, Tehran, Iran. <sup>299</sup>Occupational Health Department, Arak University of Medical Sciences, Arak, Iran. <sup>300</sup>Student Research Committee, Iran University of Medical Sciences, Tehran, Iran. <sup>301</sup>Research Group for Genomic Epidemiology, Technical University of Denmark, Copenhagen, Denmark. <sup>302</sup>Faculty of Allied Health Sciences, The University of Lahore, Lahore, Pakistan. <sup>303</sup>Afro-Asian Institute, Lahore, Pakistan. <sup>304</sup>Adelaide Medical School, University of Adelaide, Adelaide, SA, Australia. <sup>305</sup>School of Public Health and Community Medicine, University of New South Wales, Kensington, NSW, Australia. <sup>306</sup>Department of Exercise and Health Sciences, University of Massachusetts, Boston, Boston, MA, USA. <sup>307</sup>Department of Dermatology, Boston University, Boston, MA, USA. <sup>308</sup>Department of Family and Community Medicine, University of Sulaimani, Sulaimani, Iraq. <sup>309</sup>Department of Health Policy, Manipal Academy of Higher Education, Manipal, India. <sup>310</sup>Neurology, Public Health and Disability Unit, Carlo Besta Neurological Institute IRCCS (Fondazione IRCCS Istituto Neurologico Carlo Besta), Milan, Italy. <sup>311</sup>College of Medicine and Health Science, Jijiga University, Jijiga, Ethiopia. <sup>312</sup>Department of Epidemiology, Binzhou Medical University, Yantai City, China. <sup>313</sup>Non-communicable Diseases Department, World Health Organization, New Delhi, India. <sup>314</sup>Department of Preventive Cardiology, Eternal Heart Care Centre & Research Institute, Jaipur, India. <sup>315</sup>Department of Medicine, Mahatma Gandhi University Medical Sciences, Jaipur, India. <sup>316</sup>Department of Pharmacology, Tehran University of Medical Sciences, Tehran, Iran. <sup>317</sup>Obesity Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran. <sup>318</sup>Department of Family and Community Medicine, Arabian Gulf University, Manama, Bahrain. <sup>319</sup>Department of Public Health, Wachemo University,

Hossana, Ethiopia. <sup>320</sup>University Institute of Public Health, The University of Lahore, Lahore, Pakistan. <sup>321</sup>Department of Epidemiology, Airlangga University (Universitas Airlangga), Surabaya, Indonesia. <sup>322</sup>Department of Zoology and Entomology, Al Azhar University, Cairo, Egypt. <sup>323</sup>Institute for Social Science Research, The University of Queensland, Indooroopilly, QLD, Australia. <sup>324</sup>ARC Centre of Excellence for Children and Families over the Life Course, The University of Queensland, Indooroopilly, QLD, Australia. <sup>325</sup>Department of Pharmacy, University of Huddersfield, Huddersfield, UK. <sup>326</sup>School of Biomedical Sciences and Pharmacy, University of Newcastle, Newcastle, NSW, Australia. <sup>327</sup>Biology Department, Utica College, Utica, NY, USA. <sup>328</sup>Digestive Diseases Research Institute, Tehran University of Medical Sciences, Tehran, Iran. <sup>329</sup>Department of Public Health, Jigjiga University, Jijiga, Ethiopia. <sup>330</sup>Center for International Health (CIH), University of Bergen, Bergen, Norway. <sup>331</sup>Bergen Center for Ethics and Priority Setting (BCEPS), University of Bergen, Bergen, Norway. <sup>332</sup>Gastrointestinal and Liver Diseases Research Center, Guilan University of Medical Sciences, Rasht, Iran. <sup>333</sup>Caspian Digestive Disease Research Center, Guilan University of Medical Sciences, Rasht, Iran. <sup>334</sup>School of Nursing and Midwifery, Tabriz University of Medical Sciences, Tabriz, Iran. <sup>335</sup>Independent Consultant, Tabriz, Iran. <sup>336</sup>Institute of Pharmaceutical Sciences, University of Veterinary and Animal Sciences, Lahore, Pakistan. <sup>337</sup>Department of Pharmacy Administration and Clinical Pharmacy, Xian Jiaotong University, Xian, China. <sup>338</sup>School of Nursing and Midwifery, Tehran University of Medical Sciences, Tehran, Iran. <sup>339</sup>Big Data Institute, University of Oxford, Oxford, UK. <sup>340</sup>School of Business, London South Bank University, London, UK. <sup>341</sup>School of Nursing and Midwifery, Kermanshah University of Medical Sciences, Kermanshah, Iran. <sup>342</sup>Department of Public Health, Adigrat University, Adigrat, Ethiopia. <sup>343</sup>Center of Excellence in Behavioral Medicine, Nguyen Tat Thanh University, Ho Chi Minh City, Vietnam. <sup>344</sup>Kasturba Medical College, Mangalore, Manipal Academy of Higher Education, Manipal, India. <sup>345</sup>Department of Pediatrics, Yonsei University, Seoul, South Korea. <sup>346</sup>Research Department, Electronic Medical Records for the Developing World, York, UK. <sup>347</sup>Centre for Bio Cultural Studies (CBiCS), Manipal Academy of Higher Education, Manipal, India. <sup>348</sup>Deputy of Education, Iranian Ministry of Health and Medical Education, Tehran, Iran. <sup>349</sup>Institute of Research and Development, Duy Tan University, Da Nang, Vietnam. <sup>350</sup>Department of Computer Science, University of Human Development, Sulaymaniyah, Iraq. <sup>351</sup>Department of Internal Medicine, Carol Davila University of Medicine and Pharmacy, Bucharest, Romania. <sup>352</sup>Department of Legal Medicine and Bioethics, Carol Davila University of Medicine and Pharmacy, Bucharest, Romania. <sup>353</sup>Clinical Legal Medicine Department, National Institute of Legal Medicine Mina Minovici, Bucharest, Romania. <sup>354</sup>National School of Tropical Medicine, Baylor College of Medicine, Houston, TX, USA. <sup>355</sup>College of Science and Engineering, Hamad Bin Khalifa University, Doha, Qatar. <sup>356</sup>School of Public Health, University of Sydney, Sydney, NSW, Australia. <sup>357</sup>School of Nursing, Hawassa University, Hawassa, Ethiopia. <sup>358</sup>Department of Internal Medicine, Rochester General Hospital, Rochester, NY, USA. <sup>359</sup>Department of Occupational Safety and Health, China Medical University, Taichung, Taiwan. <sup>360</sup>Department of Community Medicine, University of Ibadan, Ibadan, Nigeria. <sup>361</sup>Faculty of Medicine, University of Belgrade, Belgrade, Serbia. <sup>362</sup>Department of Epidemiology, University of Kragujevac, Kragujevac, Serbia. <sup>363</sup>Division of Community Health and Family Medicine, Bangalore Baptist Hospital, Bangalore, India. <sup>364</sup>College of Public Health, Taipei Medical University, Taipei, Taiwan. <sup>365</sup>School of Psychology and Public Health, La Trobe University, Melbourne, VIC, Australia. <sup>366</sup>Institute for Physical Activity and Nutrition, Deakin University, Melbourne, VIC, Australia. <sup>367</sup>Sydney Medical School, University of Sydney, Sydney, NSW, Australia. <sup>368</sup>South African Medical Research Council, Cape Town, South Africa. <sup>369</sup>School of Health Systems and Public Health, University of Pretoria, Pretoria, South Africa. <sup>370</sup>Department of Immunology, Tabriz University of Medical Sciences, Tabriz, Iran. <sup>371</sup>Department of Internal Medicine, Cleveland Clinic, Cleveland, OH, USA. <sup>372</sup>N. A. Semashko Department of Public Health and Healthcare, I.M. Sechenov First Moscow State Medical University, Moscow, Russia. <sup>373</sup>Department of Global Health, Economics and Policy, University of Kragujevac, Kragujevac, Serbia. <sup>374</sup>Health Institute, Kermanshah University of Medical Sciences, Kermanshah, Iran. <sup>375</sup>Substance Abuse Prevention Research Center, Kermanshah University of Medical Sciences, Kermanshah, Iran. <sup>376</sup>Social Development and Health Promotion Research Center, Kermanshah University of Medical Sciences, Kermanshah, Iran. <sup>377</sup>Manipal College of Pharmaceutical Sciences, Manipal Academy of Higher Education, Manipal, India. <sup>378</sup>Health Informatic Lab, Boston University, Boston, MA, USA. <sup>379</sup>Department of Community Medicine, Baba Saheb Ambedkar Medical College & Hospital, Delhi, India. <sup>380</sup>Department of Community Medicine, Banaras Hindu University, Varanasi, India. <sup>381</sup>Renal and Cardiovascular Division, The George Institute for Global Health, New Delhi, India. <sup>382</sup>Department of Medicine, University of New South Wales, Sydney, NSW, Australia. <sup>383</sup>Department of Ophthalmology, Heidelberg University, Heidelberg, Germany. <sup>384</sup>Beijing Institute of Ophthalmology, Beijing Tongren Hospital, Beijing, China. <sup>385</sup>New South Wales Health, Sydney, NSW, Australia. <sup>386</sup>Department of Community Medicine and Family Medicine, All India Institute of Medical Sciences, Bhopal, India. <sup>387</sup>Department of Family Medicine and Public Health, University of Opole, Opole, Poland. <sup>388</sup>Minimally Invasive Surgery Research Center, Iran University of Medical Sciences, Tehran, Iran. <sup>389</sup>School of Public Health, University College Cork, Cork, Ireland. <sup>390</sup>Division of Cardiology, University of Louisville, Louisville, KY, USA. <sup>391</sup>Department of Medicine, Albert Einstein College of Medicine, Bronx, NY, USA. <sup>392</sup>School of Management and Medical Informatics, Tabriz University of Medical Sciences, Tabriz, Iran. <sup>393</sup>Institute for Prevention of Non-communicable Diseases, Qazvin University of Medical Sciences, Qazvin, Iran. <sup>394</sup>Health Services Management Department, Qazvin University of Medical Sciences, Qazvin, Iran. <sup>395</sup>Department of Pharmacology, Manipal Academy of Higher Education, Mangalore, India. <sup>396</sup>Family Medicine Department, Rafsanjan University of Medical Sciences, Rafsanjan, Iran. <sup>397</sup>Department of Forensic Medicine and Toxicology, All India Institute of Medical Sciences, Jodhpur, India. <sup>398</sup>Department of Epidemiology, Biostatistics and Clinical Research, All India Institute of Medical Sciences, New Delhi, India. <sup>399</sup>Social Determinants of Health Research Center, Tabriz University of Medical Sciences, Tabriz, Iran. <sup>400</sup>Department of Adult Health Nursing, Bahir Dar University, Bahir Dar, Ethiopia. <sup>401</sup>School of Nursing and Midwifery, Hawassa University, Hawassa, Ethiopia. <sup>402</sup>Department of Biomedical Sciences, Aksum University, Aksum, Ethiopia. <sup>403</sup>School of Midwifery, Hawassa University, Hawassa, Ethiopia. <sup>404</sup>International Research Center of Excellence, Institute of Human Virology Nigeria, Abuja, Nigeria. <sup>405</sup>Julius Centre for Health Sciences and Primary Care, Utrecht University, Utrecht, Netherlands. <sup>406</sup>Institute of Biological Chemistry and Nutrition, University Hohenheim, Stuttgart, Germany. <sup>407</sup>Open, Distance and eLearning Campus, University of Nairobi, Nairobi, Kenya. <sup>408</sup>Department of Midwifery, University of Gondar, Gondar, Ethiopia. <sup>409</sup>Department of Public Health, Debre Markos University, Debre Markos, Ethiopia. <sup>410</sup>School of Food and Agricultural Sciences, University of Management and Technology, Lahore, Pakistan. <sup>411</sup>Health Promotion Research Center, Zahedan University of Medical Sciences, Zahedan, Iran. <sup>412</sup>Department of Population Science, Jatiya Kabi Kazi Nazrul Islam University, Mymensingh, Bangladesh. <sup>413</sup>Epidemiology Department, Jazan University, Jazan, Saudi Arabia. <sup>414</sup>Department of Population Studies, International Institute for Population Sciences, Mumbai, India. <sup>415</sup>Faculty of Health and Wellbeing, Sheffield Hallam University, Sheffield, UK. <sup>416</sup>College of Arts and Sciences, Ohio University, Zanesville, OH, USA. <sup>417</sup>National Hepatology and Tropical Medicine Research Institute, Cairo University, Cairo, Egypt. <sup>418</sup>Department of Medical Parasitology, Cairo University, Cairo, Egypt. <sup>419</sup>Department of Public Health, Imam Mohammad Ibn Saud Islamic University, Riyadh, Saudi Arabia. <sup>420</sup>Department of Health Policy and Management, Johns Hopkins University, Baltimore, MD, USA. <sup>421</sup>Department of Public Health, New Mexico State University, Las Cruces, NM, USA. <sup>422</sup>Department of Public Health, Kermanshah University of Medical Sciences, Kermanshah, Iran. <sup>423</sup>Big Data Department, National Health Insurance Service, Wonju, South Korea. <sup>424</sup>School of Traditional Chinese Medicine, Xiamen University Malaysia, Sepang, Malaysia. <sup>425</sup>Department of Nutrition, Simmons University, Boston, MA, USA. <sup>426</sup>Department of Nursing and Health Promotion, Oslo Metropolitan University, Oslo, Norway. <sup>427</sup>School of Health Sciences, Kristiania University College, Oslo, Norway. <sup>428</sup>Global Community Health and Behavioral Sciences, Tulane University, New Orleans, LA, USA. <sup>429</sup>Department of Environmental Health Engineering, Arak University of Medical Sciences, Arak, Iran. <sup>430</sup>Independent Consultant, Jakarta, Indonesia. <sup>431</sup>Department of Internal and Pulmonary Medicine, Sheri Kashmir Institute of Medical Sciences, Srinagar, India. <sup>432</sup>CIBERSAM, San Juan de Dios Sanitary Park, Sant Boi de Llobregat, Spain. <sup>433</sup>Catalan Institution for Research and Advanced Studies (ICREA), Barcelona, Spain. <sup>434</sup>Department of Anthropology, Panjab University, Chandigarh, India. <sup>435</sup>Department of Anesthesiology, Duke University, Durham, NC, USA. <sup>436</sup>Department of Demography, University of Montreal, Montreal, QC, Canada. <sup>437</sup>Department of Social and Preventive Medicine, University of Montreal, Montreal, QC, Canada. <sup>438</sup>Department of Family and Community Health, University of Health and

Allied Sciences, Ho, Ghana. <sup>439</sup>International Institute for Population Sciences, Mumbai, India. <sup>440</sup>Department of Psychiatry, University of Nairobi, Nairobi, Kenya. <sup>441</sup>Division of Psychology and Language Sciences, University College London, London, UK. <sup>442</sup>Faculty of Health and Life Sciences, Coventry University, Coventry, UK. <sup>443</sup>Department of Medicine, McMaster University, Hamilton, ON, Canada. <sup>444</sup>Imperial College Business School, Imperial College London, London, UK. <sup>445</sup>Faculty of Public Health, University of Indonesia, Depok, Indonesia. <sup>446</sup>Nuffield Department of Population Health, University of Oxford, Oxford, UK. <sup>447</sup>National Institute for Health Research (NIHR) Oxford Biomedical Research Centre, Oxford, UK. <sup>448</sup>Department of Internal Medicine, Post Graduate Institute of Medical Education and Research, Chandigarh, India. <sup>449</sup>Department of Community and Family Medicine, University of Baghdad, Baghdad, Iraq. <sup>450</sup>Unit of Genetics and Public Health, Institute of Medical Sciences, Las Tablas, Panama. <sup>451</sup>Ministry of Health, Herrera, Panama. <sup>452</sup>Department of Medical Sciences, Uppsala University, Uppsala, Sweden. <sup>453</sup>Department of Clinical Chemistry and Pharmacology, Uppsala University Hospital, Uppsala, Sweden. <sup>454</sup>Department of Otorhinolaryngology, Father Muller Medical College, Mangalore, India. <sup>455</sup>School of Medicine, University of Maryland, Baltimore, MD, USA. <sup>456</sup>Department of Clinical Sciences and Community Health, University of Milan, Milan, Italy. <sup>457</sup>National Institute of Nutrition, Indian Council of Medical Research, Hyderabad, India. <sup>458</sup>School of Nursing, Hong Kong Polytechnic University, Hong Kong, China. <sup>459</sup>School of Pharmacy, Monash University, Bandar Sunway, Malaysia. <sup>460</sup>School of Pharmacy, Taylor's University Lakeside Campus, Subang Jaya, Malaysia. <sup>461</sup>Centre for Tropical Medicine and Global Health, University of Oxford, Oxford, UK. <sup>462</sup>Oxford University Clinical Research Unit, Wellcome Trust Asia Programme, Hanoi, Vietnam. <sup>463</sup>Department of Sociology, Shenzhen University, Shenzhen, China. <sup>464</sup>School of Public Health and Preventive Medicine, Monash University, Melbourne, VIC, Australia. <sup>465</sup>Department of Systems, Populations, and Leadership, University of Michigan, Ann Arbor, MI, USA. <sup>466</sup>Department of Nutrition, University of the Philippines Manila, Manila, Philippines. <sup>467</sup>Alliance for Improving Health Outcomes, Inc., Quezon City, Philippines. <sup>468</sup>Center for Integration of Data and Health Knowledge, Oswald Cruz Foundation (FIOCRUZ), Salvador, Brazil. <sup>469</sup>Centre for Global Mental Health (CGMH), London School of Hygiene & Tropical Medicine, London, UK. <sup>470</sup>Department of Biochemistry, BGS Global Institute of Medical Sciences, Bengaluru, India. <sup>471</sup>Radiology Department, Egypt Ministry of Health and Population, Mansoura, Egypt. <sup>472</sup>Ophthalmology Department, Ministry of Health & Population, Aswan, Egypt. <sup>473</sup>Department of Forensic Medicine & Toxicology, Mysore Medical College & Research Institute, Mysore, India. <sup>474</sup>Department of Health & Family Welfare, Government of Karnataka, Bangalore, India. <sup>475</sup>Grants, Innovation and Product Development Unit, South African Medical Research Council, Cape Town, South Africa. <sup>476</sup>Department of Public Health, Urmia University of Medical Science, Urmia, Iran. <sup>477</sup>Department of Clinical Physiology, Tribhuvan University, Kathmandu, Nepal. <sup>478</sup>Department of Forensic Medicine, Rajiv Gandhi University of Health Sciences, Dharwad, India. <sup>479</sup>Department of Forensic Medicine, Shri Dharmasthala Manjunatheshwara University, Dharwad, India. <sup>480</sup>Clinical Research Development Center, Kermanshah University of Medical Sciences, Kermanshah, Iran. <sup>481</sup>Non-communicable Disease Research Center, Shiraz University of Medical Sciences, Shiraz, Iran. <sup>482</sup>Department of Maternal and Child Nursing and Public Health, Federal University of Minas Gerais, Belo Horizonte, Brazil. <sup>483</sup>Department of Epidemiology and Biostatistics, Tehran University of Medical Sciences, Tehran, Iran. <sup>484</sup>Department of Nursing, Majmaah University, Majmaah, Saudi Arabia. <sup>485</sup>Technological Institution Colegio Mayor de Bolívar (Institución Tecnológica Colegio Mayor de Bolívar), Cartagena, Colombia. <sup>486</sup>Campus Caucaia, Federal Institute of Education, Science and Technology of Ceará, Caucaia, Brazil. <sup>487</sup>Faculty of Health and Education, Botho University, Gaborone, Botswana. <sup>488</sup>Research Division, The George Institute for Global Health, New Delhi, India. <sup>489</sup>School of Medicine, University of New South Wales, Sydney, NSW, Australia. <sup>490</sup>ICF International, DHS Program, Rockville, MD, USA. <sup>491</sup>Department of Epidemiology, Adigrat University, Adigrat, Ethiopia. <sup>492</sup>Neurology Department, Janakpuri Super Speciality Hospital Society, New Delhi, India. <sup>493</sup>Department of Neurology, Govind Ballabh Institute of Medical Education and Research, New Delhi, India. <sup>494</sup>Tehran Heart Center, Tehran University of Medical Sciences, Tehran, Iran. <sup>495</sup>Nutrition Health Research Center, Iran University of Medical Sciences, Hamadan, Iran. <sup>496</sup>Department of Epidemiology and Biostatistics, University of California, San Francisco, San Francisco, CA, USA. <sup>497</sup>Department of Public Health and Mortality Studies, International Institute for Population Sciences, Mumbai, India. <sup>498</sup>Department of Nutrition, University of Oslo, Oslo, Norway. <sup>499</sup>Department of Hematology and Immunohematology, University of Gondar, Gondar, Ethiopia. <sup>500</sup>Peru Country Office, United Nations Population Fund (UNFPA), Lima, Peru. <sup>501</sup>Forensic Medicine Division, Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia. <sup>502</sup>Department of Midwifery, Adigrat University, Adigrat, Ethiopia. <sup>503</sup>Department of Reproductive Health and Population Studies, Bahir Dar University, Bahir Dar, Ethiopia. <sup>504</sup>Breast Surgery Unit, Helsinki University Hospital, Helsinki, Finland. <sup>505</sup>University of Helsinki, Helsinki, Finland. <sup>506</sup>Department of Nursing, Arba Minch University, Arba Minch, Ethiopia. <sup>507</sup>Department of Psychiatry, Mekelle University, Mekelle, Ethiopia. <sup>508</sup>Department of Propedeutics of Internal Diseases & Arterial Hypertension, Pomeranian Medical University, Szczecin, Poland. <sup>509</sup>Woman-Mother-Child Department, Lausanne University Hospital, Lausanne, Switzerland. <sup>510</sup>Global Institute of Public Health, Ananthapuri Hospitals and Research Institute, Trivandrum, India. <sup>511</sup>College of Applied Medical Sciences, Majmaah University, Riyadh, Saudi Arabia. <sup>512</sup>Internal Medicine Programme, Kyrgyz State Medical Academy, Bishkek, Kyrgyzstan. <sup>513</sup>Department of Atherosclerosis and Coronary Heart Disease, National Center of Cardiology and Internal Disease, Bishkek, Kyrgyzstan. <sup>514</sup>Research Center for Biochemistry and Nutrition in Metabolic Diseases, Kashan University of Medical Sciences, Kashan, Iran. <sup>515</sup>Department of Rehabilitation and Sports Medicine, Kermanshah University of Medical Sciences, Kermanshah, Iran. <sup>516</sup>Department of Surgical Oncology, All India Institute of Medical Sciences, Jodhpur, India. <sup>517</sup>Institute of Addiction Research (ISFF), Frankfurt University of Applied Sciences, Frankfurt, Germany. <sup>518</sup>Biotechnology Research Center, Tabriz University of Medical Sciences, Tabriz, Iran. <sup>519</sup>Molecular Medicine Research Center, Tabriz University of Medical Sciences, Tabriz, Iran. <sup>520</sup>Internal Medicine Department, King Saud University, Riyadh, Saudi Arabia. <sup>521</sup>Department of Forestry, Salahaddin University-Erbil, Erbil, Iraq. <sup>522</sup>Department of Medicine-Huddinge, Karolinska Institute, Stockholm, Sweden. <sup>523</sup>Department of Biostatistics, Hamadan University of Medical Sciences, Hamadan, Iran. <sup>524</sup>Department of Anatomical Sciences, Zanjan University of Medical Sciences, Zanjan, Iran. <sup>525</sup>Department of Epidemiology and Biostatistics, Shahrekord University of Medical Sciences, Shahrekord, Iran. <sup>526</sup>Department of Nursing, Mashhad University of Medical Sciences, Mashhad, Iran. <sup>527</sup>Department of Nursing, Adigrat University, Adigrat, Ethiopia. <sup>528</sup>Department of Biomolecular Sciences, University of Mississippi, Oxford, MS, USA. <sup>529</sup>Department of Pharmacy, Mizan-Tepi University, Mizan, Ethiopia. <sup>530</sup>School of Pharmacy, Haramaya University, Harar, Ethiopia. <sup>531</sup>Health Systems and Policy Research Unit, Ahmadu Bello University, Zaria, Nigeria. <sup>532</sup>Department of Public Health, Samara University, Semera, Ethiopia. <sup>533</sup>Pediatric Neurorehabilitation Research Center, University of Social Welfare and Rehabilitation Sciences, Tehran, Iran. <sup>534</sup>Clinical Epidemiology and Public Health Research Unit, Burlo Garofolo Institute for Maternal and Child Health, Trieste, Italy. <sup>535</sup>Computer, Electrical, and Mathematical Sciences and Engineering Division, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia. <sup>536</sup>Department of Clinical Biochemistry, Babol University of Medical Sciences, Babol, Iran. <sup>537</sup>Department of Clinical Biochemistry, Tarbiat Modares University, Tehran, Iran. <sup>538</sup>Department of Health Policy, Management, and Economics, Tehran University of Medical Sciences, Tehran, Iran. <sup>539</sup>Department of Food Science, University of Campinas (Unicamp), Campinas, Brazil. <sup>540</sup>Department of Pediatrics and Child Health, Debre Berhan University, Debre Berhan, Ethiopia. <sup>541</sup>Department of Community Health Sciences, Fatima Memorial Hospital (FMH), Lahore, Pakistan. <sup>542</sup>School of Economics, University of Nairobi, Nairobi, Kenya. <sup>543</sup>Indian Institute of Public Health, Public Health Foundation of India, Hyderabad, India. <sup>544</sup>Department of Pediatric Medicine, The Children's Hospital & The Institute of Child Health, Multan, Pakistan. <sup>545</sup>Department of Pediatrics & Pediatric Pulmonology, Institute of Mother & Child Care, Multan, Pakistan. <sup>546</sup>Department of Obstetrics and Gynecology, Ain Shams University, Cairo, Egypt. <sup>547</sup>Knowledge Translation and Utilization, Egyptian Center for Evidence Based Medicine, Cairo, Egypt. <sup>548</sup>Research and Analytics Department, Initiative for Financing Health and Human Development, Chennai, India. <sup>549</sup>Department of Research and Analytics, Bioinsilico Technologies, Chennai, India. <sup>550</sup>Department of Nephrology, Manipal Academy of Higher Education, Manipal, India. <sup>551</sup>Comprehensive Cancer Center, University of Alabama at Birmingham, Birmingham, AL, USA. <sup>552</sup>Laboratory of Public Health Indicators Analysis and Health Digitalization, Moscow Institute of Physics and Technology, Dolgoprudny, Russia. <sup>553</sup>Experimental Surgery and Oncology Laboratory, Kursk State Medical University, Kursk, Russia. <sup>554</sup>Suraj Eye

Institute, Nagpur, India. <sup>555</sup>Department for the Control of Disease, Epidemics, and Pandemics, Ministry of Public Health, Yaoundé, Cameroon. <sup>556</sup>Department of Public Health, University of Yaoundé I, Yaoundé, Cameroon. <sup>557</sup>Department of Pharmacy Practice, Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia. <sup>558</sup>Discipline of Social & Administrative Pharmacy, University of Science Malaysia, Penang, Malaysia. <sup>559</sup>Department of Clinical Medicine, Federal University of Minas Gerais, Belo Horizonte, Brazil. <sup>560</sup>Clinical Hospital, Federal University of Minas Gerais, Belo Horizonte, Brazil. <sup>561</sup>Manipal Institute of Management, Manipal Academy of Higher Education, Manipal, India. <sup>562</sup>Department of Pediatrics, Arak University of Medical Sciences, Arak, Iran. <sup>563</sup>Disease Control and Environmental Health, Makerere University, Kampala, Uganda. <sup>564</sup>Department of General Surgery, Carol Davila University of Medicine and Pharmacy, Bucharest, Romania. <sup>565</sup>Department of General Surgery, Emergency Hospital of Bucharest, Bucharest, Romania. <sup>566</sup>Department of Anatomy and Embryology, Carol Davila University of Medicine and Pharmacy, Bucharest, Romania. <sup>567</sup>Cardio-Aid, Bucharest, Romania. <sup>568</sup>School of Nursing, University of Gondar, Gondar, Ethiopia. <sup>569</sup>School of Health Sciences, Surgical Nursing, Bahir Dar University, Gondar, Ethiopia. <sup>570</sup>Department of Biological Sciences, University of Embu, Embu, Kenya. <sup>571</sup>Institute for Global Health Innovations, Duy Tan University, Hanoi, Vietnam. <sup>572</sup>Faculty of Pharmacy, Duy Tan University, Da Nang, Vietnam. <sup>573</sup>Institute for Mental Health and Policy, Centre for Addiction and Mental Health, Toronto, ON, Canada. <sup>574</sup>Department of Clinical Epidemiology, Institute for Clinical Evaluative Sciences, Ottawa, ON, Canada. <sup>575</sup>Hormozgan University of Medical Sciences, Bandar Abbas, Iran. <sup>576</sup>School of Public Health and Family Medicine, University of Cape Town, Cape Town, South Africa. <sup>577</sup>Centre for Heart Rhythm Disorders, University of Adelaide, Adelaide, WC, Australia. <sup>578</sup>Unit of Microbiology and Public Health, Institute of Medical Sciences, Las Tablas, Panama. <sup>579</sup>Department of Public Health, Ministry of Health, Herrera, Panama. <sup>580</sup>Department of Pediatrics, National Hospital Abuja, Abuja, Nigeria. <sup>581</sup>Department of International Public Health, University of Liverpool, Liverpool, UK. <sup>582</sup>Department of Public Health, CQ University, Melbourne, VIC, Australia. <sup>583</sup>Administrative and Economic Sciences Department, University of Bucharest, Bucharest, Romania. <sup>584</sup>Translational Health Research Institute, Western Sydney University, Sydney, NSW, Australia. <sup>585</sup>Department of Obstetrics and Gynecology, University of Ibadan, Ibadan, Nigeria. <sup>586</sup>Department of Preventive Medicine, Kyung Hee University, Dongdaemun-gu, South Korea. <sup>587</sup>Department of Rural Development and Agribusiness, Gulu University, Gulu, Uganda. <sup>588</sup>Gorgan Congenital Malformations Research Center, Golestan University of Medical Sciences, Gorgan, Iran. <sup>589</sup>Department of Psychiatry and Behavioural Neurosciences, McMaster University, Hamilton, ON, Canada. <sup>590</sup>Department of Psychiatry, University of Lagos, Lagos, Nigeria. <sup>591</sup>Centre for Healthy Start Initiative, Lagos, Nigeria. <sup>592</sup>Diplomacy and Public Relations Department, University of Human Development, Sulaimaniyah, Iraq. <sup>593</sup>Department of Anatomic Pathology, Ekiti State University Teaching Hospital, Ado Ekiti, Nigeria. <sup>594</sup>Department of Pharmacology and Therapeutics, University of Nigeria Nsukka, Enugu, Nigeria. <sup>595</sup>Department of Medicine, Autonomous University of Madrid, Madrid, Spain. <sup>596</sup>Department of Nephrology and Hypertension, The Institute for Health Research Foundation, Jiménez Díaz University Hospital, Madrid, Spain. <sup>597</sup>Center for Population Health Research, National Institute of Public Health, Cuernavaca, Mexico. <sup>598</sup>Department of Project Management, National Research University Higher School of Economics, Moscow, Russia. <sup>599</sup>Department of Medicine, University of Ibadan, Ibadan, Nigeria. <sup>600</sup>Department of Medicine, University College Hospital, Ibadan, Ibadan, Nigeria. <sup>601</sup>Department of Respiratory Medicine, Jagadguru Sri Shivarathreeswara Academy of Health Education and Research, Mysore, India. <sup>602</sup>Department of Forensic Medicine, Manipal Academy of Higher Education, Mangalore, India. <sup>603</sup>Department of Parasitology and Mycology, Shiraz University of Medical Sciences, Shiraz, Iran. <sup>604</sup>Department of Health Metrics, Center for Health Outcomes & Evaluation, Bucharest, Romania. <sup>605</sup>Department of Research, Public Health Foundation of India, Gurugram, India. <sup>606</sup>Somnogen Canada Inc, Toronto, ON, Canada. <sup>607</sup>National Institute of Health Research and Development, Ministry of Health, Jakarta, Indonesia. <sup>608</sup>Division of General Internal Medicine, University of Pittsburgh Medical Center, Pittsburgh, PA, USA. <sup>609</sup>Department of Poverty, Gender and Youth, Population Council, New Delhi, India. <sup>610</sup>Department of Neurology and Public Health, Icahn School of Medicine at Mount Sinai, New York, NY, USA. <sup>611</sup>Department of Pediatrics, RD Gardi Medical College, Ujjain, India. <sup>612</sup>Global Public Health-Health Systems and Policy (HSP): Medicines Focusing Antibiotics, Karolinska Institute, Stockholm, Sweden. <sup>613</sup>Department of Pediatrics, University of Melbourne, Melbourne, VIC, Australia. <sup>614</sup>Population Health Theme, Murdoch Children's Research Institute, Melbourne, VIC, Australia. <sup>615</sup>Department of Physiology, Iran University of Medical Sciences, Tehran, Iran. <sup>616</sup>Physiology Research Center, Iran University of Medical Sciences, Tehran, Iran. <sup>617</sup>Department of Orthopedics, Yenepoya Medical College, Mangalore, India. <sup>618</sup>Department of Biochemistry and Dietetics, Tabriz University of Medical Sciences, Tabriz, Iran. <sup>619</sup>HIV and Mental Health Department, Integrated Development Foundation Nepal, Kathmandu, Nepal. <sup>620</sup>University Medical Center Groningen, University of Groningen, Groningen, Netherlands. <sup>621</sup>School of Economics and Business, University of Groningen, Groningen, Netherlands. <sup>622</sup>Department of Pharmacology, Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia. <sup>623</sup>Clinical Research Development Centre, Taleghani and Imam Ali Hospital, Kermanshah University of Medical Sciences, Kermanshah, Iran. <sup>624</sup>Department of Nutrition and Food Sciences, Maragheh University of Medical Sciences, Maragheh, Iran. <sup>625</sup>Dietary Supplements and Probiotic Research Center, Alborz University of Medical Sciences, Karaj, Iran. <sup>626</sup>Clinical Research Center, Valle del Lili Foundation (Centro de Investigaciones Clínicas, Fundación Valle del Lili), Cali, Colombia. <sup>627</sup>PROESA, ICESI University (Centro PROESA, Universidad ICESI), Cali, Colombia. <sup>628</sup>Health Sciences Department, Muhammadiyah University of Surakarta, Sukoharjo, Indonesia. <sup>629</sup>Department of Chemistry, Sharif University of Technology, Tehran, Iran. <sup>630</sup>Department of Medicine, University of Alberta, Edmonton, AB, Canada. <sup>631</sup>Thalassemia and Hemoglobinopathy Research Center, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran. <sup>632</sup>Metabolomics and Genomics Research Center, Tehran University of Medical Sciences, Tehran, Iran. <sup>633</sup>Department of Community Medicine, Maharishi Markandeshwar Medical College & Hospital, Solan, India. <sup>634</sup>School of Nursing and Healthcare Professions, Federation University Australia, Berwick, VIC, Australia. <sup>635</sup>Department of Computer Science, Khazar University, Baku, Azerbaijan. <sup>636</sup>Society for Health and Demographic Surveillance, Suri, India. <sup>637</sup>Department of Economics, University of Göttingen, Göttingen, Germany. <sup>638</sup>Department of Surgery, The University of Texas Health Science Center at San Antonio, San Antonio, TX, USA. <sup>639</sup>Department of Cardiology, Emory University, Atlanta, GA, USA. <sup>640</sup>Department of Pharmacology, Shahid Beheshti University of Medical Sciences, Tehran, Iran. <sup>641</sup>Research Department, Policy Research Institute, Kathmandu, Nepal. <sup>642</sup>Health and Public Policy Department, Global Center for Research and Development, Kathmandu, Nepal. <sup>643</sup>Department of Oral Pathology, Srinivas Institute of Dental Sciences, Mangalore, India. <sup>644</sup>Department of Infectious Disease, Manipal Academy of Higher Education, Mangalore, India. <sup>645</sup>Department of Forensic Medicine and Toxicology, Manipal Academy of Higher Education, Mangalore, India. <sup>646</sup>School of Health, Medical and Applied Sciences, CQ University, Sydney, NSW, Australia. <sup>647</sup>River Region Cardiology Associates, Montgomery, WV, USA. <sup>648</sup>Department of Computer Science, Boston University, Boston, MA, USA. <sup>649</sup>Department of Health Information Management, Manipal Academy of Higher Education, Manipal, India. <sup>650</sup>Manipal Academy of Higher Education, Manipal, India. <sup>651</sup>Network of Immunity in Infection, Malignancy and Autoimmunity (NIIMA), Universal Scientific Education and Research Network (USERN), Tehran, Iran. <sup>652</sup>Department of Infectious Diseases, University of Copenhagen, Copenhagen, Denmark. <sup>653</sup>Cardiovascular Diseases Research Center, Birjand University of Medical Sciences, Birjand, Iran. <sup>654</sup>Department of Chemical Sciences, University of Porto, Oporto, Portugal. <sup>655</sup>Epidemiology Research Unit Institute of Public Health (EPIUnit-ISPUP), University of Porto, Porto, Portugal. <sup>656</sup>Department of Surgery, University of Minnesota, Minneapolis, MN, USA. <sup>657</sup>Department of Surgery, University Teaching Hospital of Kigali, Kigali, Rwanda. <sup>658</sup>Department of Clinical Research, Federal University of Uberlândia, Uberlândia, Brazil. <sup>659</sup>School of Medicine, Gonabad University of Medical Sciences, Gonabad, Iran. <sup>660</sup>Malaria Atlas Project, University of Oxford, Oxford, UK. <sup>661</sup>Department of Health Statistics, National Institute for Medical Research, Dar es Salaam, Tanzania. <sup>662</sup>Department of Internal Medicine, University of Botswana, Gaborone, Botswana. <sup>663</sup>Department of Epidemiology, Shahid Beheshti University of Medical Sciences, Tehran, Iran. <sup>664</sup>Department of Psychiatry, All India Institute of Medical Sciences, New Delhi, India. <sup>665</sup>Halal Research Center of IRI, Food and Drug Administration of the Islamic Republic of Iran, Tehran, Iran. <sup>666</sup>Neurogenic Inflammation Research Center, Mashhad University of Medical Sciences, Mashhad, Iran. <sup>667</sup>Department of Phytochemistry, Soran University, Soran, Iraq. <sup>668</sup>Department of Nutrition, Cihan University-Erbil, Erbil, Iraq. <sup>669</sup>Department of Microbiology, Central

University of Punjab, Bathinda, India. <sup>670</sup>Public Health and Community Medicine Department, Cairo University, Giza, Egypt. <sup>671</sup>Drug Applied Research Center, Tabriz University of Medical Sciences, Tabriz, Iran. <sup>672</sup>Center for Clinical and Epidemiological Research, Hospital Universitário, University of São Paulo, São Paulo, Brazil. <sup>673</sup>School of Public Health and Health Management, University of Belgrade, Belgrade, Serbia. <sup>674</sup>Department of Community Medicine, PSG Institute of Medical Sciences and Research, Coimbatore, India. <sup>675</sup>PSG-FAIMER South Asia Regional Institute, Coimbatore, India. <sup>676</sup>Isfahan Cardiovascular Research Institute, Isfahan University of Medical Sciences, Isfahan, Iran. <sup>677</sup>School of Population and Public Health, University of British Columbia, Vancouver, BC, Canada. <sup>678</sup>Faculty of Infectious and Tropical Diseases, London School of Hygiene & Tropical Medicine, London, UK. <sup>679</sup>Colorectal Research Center, Iran University of Medical Sciences, Tehran, Iran. <sup>680</sup>Department of Geriatrics and Long Term Care, Hamad Medical Corporation, Doha, Qatar. <sup>681</sup>Faculty of Health & Social Sciences, Bournemouth University, Bournemouth, UK. <sup>682</sup>Population Health Research Institute, McMaster University, Hamilton, ON, Canada. <sup>683</sup>Department of Epidemiology, Indian Institute of Public Health, Gandhinagar, India. <sup>684</sup>Department of Psychology, University of Alabama at Birmingham, Birmingham, AL, USA. <sup>685</sup>Department of Food Science and Nutrition, Jigjiga University, Jigjiga, Ethiopia. <sup>686</sup>Department of Computational Biology, Indraprastha Institute of Information Technology, Delhi, India. <sup>687</sup>Emergency Department, Manian Medical Centre, Erode, India. <sup>688</sup>National Heart, Lung, and Blood Institute, National Institutes of Health, Rockville, MD, USA. <sup>689</sup>Center for Biomedical Information Technology, Shenzhen Institutes of Advanced Technology, Shenzhen, China. <sup>690</sup>Department of Radiology and Radiological Science, Johns Hopkins University, Baltimore, MD, USA. <sup>691</sup>Department of Radiology and Interventional Neuroradiology, Isfahan University of Medical Sciences, Isfahan, Iran. <sup>692</sup>Health Policy Research Center, Shiraz University of Medical Sciences, Shiraz, Iran. <sup>693</sup>Department of Internal Medicine, Ziauddin University, Karachi, Pakistan. <sup>694</sup>Independent Consultant, Karachi, Pakistan. <sup>695</sup>School of Public Health, Dilla University, Dilla, Ethiopia. <sup>696</sup>Neurology Department, Ain Shams University, Cairo, Egypt. <sup>697</sup>Department of Clinical Research, University of Southern Denmark, Odense, Denmark. <sup>698</sup>School of Medicine, Alborz University of Medical Sciences, Karaj, Iran. <sup>699</sup>Faculty of Caring Science, Work Life, and Social Welfare, University of Borås, Borås, Sweden. <sup>700</sup>Department of Community Medicine, BLDE University, Vijayapur, India. <sup>701</sup>Golestan Research Center of Gastroenterology and Hepatology (GRCGH), Golestan University of Medical Sciences, Gorgan, Iran. <sup>702</sup>Centre for Medical Informatics, University of Edinburgh, Edinburgh, UK. <sup>703</sup>Division of General Internal Medicine, Harvard University, Boston, MA, USA. <sup>704</sup>Health Information Management, Iran University of Medical Sciences, Tehran, Iran. <sup>705</sup>Department of Community Medicine, Manipal Academy of Higher Education, Manipal, India. <sup>706</sup>Department of Obstetrics and Gynaecology, Manipal Academy of Higher Education, Mangalore, India. <sup>707</sup>National Institute of Infectious Diseases, Tokyo, Japan. <sup>708</sup>College of Medicine, Yonsei University, Seoul, South Korea. <sup>709</sup>Finnish Institute of Occupational Health, Helsinki, Finland. <sup>710</sup>Cancer Research Institute, Tehran University of Medical Sciences, Tehran, Iran. <sup>711</sup>Cancer Biology Research Center, Tehran University of Medical Sciences, Tehran, Iran. <sup>712</sup>Clinical Immunology and Hematology, Sofamed University Hospital, Sofia, Bulgaria. <sup>713</sup>Department of Genetics, Sofia University 'St. Kliment Ohridski', Sofia, Bulgaria. <sup>714</sup>Department of Health Education and Health Promotion, Kermanshah University of Medical Sciences, Kermanshah, Iran. <sup>715</sup>School of Health, University of Technology Sydney, Sydney, NSW, Australia. <sup>716</sup>Department of Hematology-Oncology, Baystate Medical Center, Springfield, MA, USA. <sup>717</sup>Department of Medicine, Dow University of Health Sciences, Karachi, Pakistan. <sup>718</sup>School of Public Health & Zoonoses, Guru Angad Dev Veterinary & Animal Sciences University, Ludhiana, India. <sup>719</sup>School of Veterinary Science, University of Sydney, Sydney, NSW, Australia. <sup>720</sup>Division of Environmental Monitoring & Exposure Assessment (Water & Soil), National Institute for Research in Environmental Health, Bhopal, India. <sup>721</sup>Department of Midwifery, Haramaya University, Harar, Ethiopia. <sup>722</sup>Department No. 16, Moscow Research and Practical Centre on Addictions, Moscow, Russia. <sup>723</sup>Therapeutic Department, Balashiha Central Hospital, Balashikha, Russia. <sup>724</sup>Department of Vascular and Endovascular Surgery, Kermanshah University of Medical Sciences, Kermanshah, Iran. <sup>725</sup>Nursing Care Research Center, Semnan University of Medical Sciences, Semnan, Iran. <sup>726</sup>Division of Community Medicine, International Medical University, Kuala Lumpur, Malaysia. <sup>727</sup>Nursing Department, Muhammadiyah University of Surakarta, Surakarta, Indonesia. <sup>728</sup>Pediatric Services, King Hussein Cancer Center, Amman, Jordan. <sup>729</sup>Pediatrics, University of Jordan, Amman, Jordan. <sup>730</sup>Department of Medicine, University of Valencia, Valencia, Spain. <sup>731</sup>Carlos III Health Institute, Biomedical Research Networking Center for Mental Health Network (CiberSAM), Madrid, Spain. <sup>732</sup>Cancer Control Center, Osaka International Cancer Institute, Osaka, Japan. <sup>733</sup>Department of Pharmacy, Arbaminch College of Health Sciences, Arba Minch, Ethiopia. <sup>734</sup>Department of Biomedical Sciences, Arba Minch University, Arba Minch, Ethiopia. <sup>735</sup>Research Center for Molecular Medicine, Hamadan University of Medical Sciences, Hamadan, Iran. <sup>736</sup>Department of Medical Laboratory Science, Addis Ababa University, Addis Ababa, Ethiopia. <sup>737</sup>Department of Population Science and Human Resource Development, University of Rajshahi, Rajshahi, Bangladesh. <sup>738</sup>Department of Cell Therapy and Applied Genomics, King Hussein Cancer Center, Amman, Jordan. <sup>739</sup>Department of Clinical Pharmacy, University of Gondar, Gondar, Ethiopia. <sup>740</sup>Department of Community and Family Medicine, Iran University of Medical Sciences, Tehran, Iran. <sup>741</sup>Pediatric Intensive Care Unit, King Saud University, Riyadh, Saudi Arabia. <sup>742</sup>Department of Public Health and Community Medicine, Central University of Kerala, Kasargod, India. <sup>743</sup>Department of Endocrinology, Diabetes and Metabolism, Christian Medical College and Hospital (CMC), Vellore, India. <sup>744</sup>Department of Psychiatry Nursing, Ambo University, Ambo, Ethiopia. <sup>745</sup>K.A. Timiryazev Institute of Plant Physiology, Russian Academy of Sciences, Moscow, Russia. <sup>746</sup>Department of Pathology and Legal Medicine, University of São Paulo, Ribeirão Preto, Brazil. <sup>747</sup>Modestum LTD, London, UK. <sup>748</sup>Molecular Medicine and Pathology, University of Auckland, Auckland, New Zealand. <sup>749</sup>Clinical Hematology and Toxicology, Maurice Wilkins Centre, Auckland, New Zealand. <sup>750</sup>Department of Health Economics, Hanoi Medical University, Hanoi, Vietnam. <sup>751</sup>Department of Zoology, Arabian Gulf University, Churu, India. <sup>752</sup>Department of Community Medicine, All India Institute of Medical Sciences, Nagpur, India. <sup>753</sup>Faculty of Geo-Information Science and Earth Observation, University of Twente, Enschede, Netherlands. <sup>754</sup>School of Health and Rehabilitation Sciences, The University of Queensland, Brisbane, QLD, Australia. <sup>755</sup>Multidisciplinary Department, National University of Medical Sciences (NUMS), Rawalpindi, Pakistan. <sup>756</sup>Department of Community Medicine, Alex Ekwueme Federal University Teaching Hospital Abakaliki, Abakaliki, Nigeria. <sup>757</sup>Department of Medical Microbiology/Parasitology, Ebonyi State University, Abakaliki, Nigeria. <sup>758</sup>Kasturba Medical College, Manipal Academy of Higher Education, Mangalore, India. <sup>759</sup>Amity Institute of Biotechnology, Amity University Rajasthan, Jaipur, India. <sup>760</sup>Department of Internal Medicine, Dow University of Health Sciences, Karachi, Pakistan. <sup>761</sup>Department of Neurology, Rafsanjan University of Medical Sciences, Rafsanjan, Iran. <sup>762</sup>Non-communicable Diseases Research Center, Rafsanjan University of Medical Sciences, Rafsanjan, Iran. <sup>763</sup>Clinical Cancer Research Center, Milad General Hospital, Tehran, Iran. <sup>764</sup>Department of Microbiology, Islamic Azad University, Tehran, Iran. <sup>765</sup>Argentine Society of Medicine, Buenos Aires, Argentina. <sup>766</sup>Velez Sarsfield Hospital, Buenos Aires, Argentina. <sup>767</sup>Department of Community Medicine and Family Medicine, All India Institute of Medical Sciences, Bathinda, India. <sup>768</sup>Department of Medical and Surgical Sciences, University of Bologna, Bologna, Italy. <sup>769</sup>Occupational Health Unit, Sant'Orsola Malpighi Hospital, Bologna, Italy. <sup>770</sup>Faculty of Information Technology, Ho Chi Minh City University of Technology (HUTECH), Ho Chi Minh City, Vietnam. <sup>771</sup>Population Dynamics and Sexual and Reproductive Health, African Population and Health Research Center, Nairobi, Kenya. <sup>772</sup>Foundation University Medical College, Foundation University Islamabad, Islamabad, Pakistan. <sup>773</sup>Department of Epidemiology and Biostatistics, Wuhan University, Wuhan, China. <sup>774</sup>Research School of Population Health, Australian National University, Canberra, ACT, Australia. <sup>775</sup>Demographic Change and Aging Research Area, Federal Institute for Population Research, Wiesbaden, Germany. <sup>776</sup>Department of Physical Therapy, Naresuan University, Phitsanulok, Thailand. <sup>777</sup>Department of Community Medicine, Rajarata University of Sri Lanka, Anuradhapura, Sri Lanka. <sup>778</sup>Department of Orthopaedics, Wenzhou Medical University, Wenzhou, China. <sup>779</sup>Global Health Research Center, Duke Kunshan University, Kunshan, China. <sup>780</sup>Duke Global Health Institute, Duke University, Durham, NC, USA. <sup>781</sup>Department of Behavior and Operation Management, Beijing Advanced Innovation Center for Big Data-based Precision Medicine, Beijing, China. <sup>782</sup>Psychology Department, University of Sheffield, Sheffield, UK. <sup>783</sup>Department of Diabetes and Metabolic Diseases, University of Tokyo, Tokyo, Japan. <sup>784</sup>School of International Development and Global Studies, University of Ottawa, Ottawa, ON, Canada. <sup>785</sup>The George Institute for Global Health, University of Oxford, Oxford, UK. <sup>786</sup>Health Services Management Research Center,

Kerman University of Medical Sciences, Kerman, Iran. <sup>787</sup>Department of Health Management, Policy, and Economics, Kerman University of Medical Sciences, Kerman, Iran. <sup>788</sup>Centre for Suicide Research and Prevention, University of Hong Kong, Hong Kong, China. <sup>789</sup>Department of Social Work and Social Administration, University of Hong Kong, Hong Kong, China. <sup>790</sup>Hubert Department of Global Health, Emory University, Atlanta, GA, USA. <sup>791</sup>Department of Environmental Health, Mazandaran University of Medical Sciences, Sari, Iran. <sup>792</sup>Injury Prevention and Safety Promotion Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran. <sup>793</sup>School of Public Health and Management, Hubei University of Medicine, Shiyan, China. <sup>794</sup>Department of Obstetrics and Gynaecology, Fazaia Medical College, Islamabad, Pakistan. <sup>795</sup>Department of Obstetrics and Gynaecology, Air University, Islamabad, Pakistan. <sup>796</sup>Department of Pharmaceutics, Dow University of Health Sciences, Karachi, Pakistan. <sup>797</sup>Department of Medicine, University Ferhat Abbas of Setif, Sétif, Algeria. <sup>798</sup>Institute for Immunological Research, University of Cartagena, Cartagena, Colombia. <sup>799</sup>The School of Clinical Sciences at Monash Health, Monash University, Melbourne, VIC, Australia. <sup>800</sup>Student Research Committee, Babol University of Medical Sciences, Babol, Iran. <sup>801</sup>Department of Radiology, Children's Hospital of Philadelphia, Philadelphia, PA, USA. <sup>802</sup>Laboratory of Genetics and Genomics, Moscow Research and Practical Centre on Addictions, Moscow, Russia. <sup>803</sup>Addictology Department, Russian Medical Academy of Continuous Professional Education, Moscow, Russia. <sup>804</sup>Pediatrics Department, Russian Medical Academy of Continuous Professional Education, Moscow, Russia. <sup>805</sup>Department of Psychiatric Nursing, Haramaya University, Harar, Ethiopia. <sup>806</sup>School of Pharmacy, Mekelle University, Mekelle, Ethiopia. <sup>807</sup>School of Public Health, Wuhan University of Science and Technology, Wuhan, China. <sup>808</sup>Hubei Province Key Laboratory of Occupational Hazard Identification and Control, Wuhan University of Science and Technology, Wuhan, China. <sup>809</sup>Department of Epidemiology, Human Genetics, and Environmental Sciences, The University of Texas Health Science Center at Houston, Houston, TX, USA.

## Methods

**Overview.** This study implemented continuous geostatistics modeling of mild, moderate and severe anemia prevalence over time, from which local-, administrative- and national-level estimates of prevalence, counts and all other estimated quantities were derived. An ensemble approach using a Bayesian generalized linear mixed effects model was used to embed non-linear algorithmically predicted mean functions within a Gaussian process framework, assumed to have a correlated space–time covariance structure. We sampled 1,000 draws from an approximate posterior distribution of this model and generated annual prevalence estimates for mild, moderate, and severe anemia prevalence of WRA (ages 15–49 years) on an approximate 5 × 5-km grid over 82 LMICs from 2000 to 2018 and performed population-weighted aggregation of these gridded estimates to administrative and national levels. Countries were selected for inclusion in this study using the SDI, a summary measure of development that combines education, fertility and poverty<sup>18</sup>. Selected countries were in the low, lower-middle and middle SDI quintiles, with several exceptions (Supplementary Table 3). China, Malaysia and Turkmenistan were included despite high-middle SDIs for geographic continuity with other included countries. Albania, Bosnia-Herzegovina, North Korea and Moldova were excluded due to geographic discontinuity and lack of available survey data. Of this set of countries, we did not generate estimates for 26 countries, as no survey data could be sourced (Supplementary Table 4).

**Data. Surveys and hemoglobin data.** We extracted each individual woman's hemoglobin concentrations (g L<sup>-1</sup>), age, pregnancy status, smoking status and elevation from household series, including the Demographic and Health Surveys, the Multiple Indicator Cluster Surveys, the Living Standards Measurement Study and the Core Welfare Indicators Questionnaire, among other country-specific child health and nutrition surveys. Included across our models were 218 geo-referenced household surveys from 2000 to 2018 representing over 3 million WRA. Each individual woman's record was associated with a cluster, a group of neighboring households or a 'community' that acted as a primary sampling unit in the survey design. The 218 surveys with hemoglobin, pregnancy, smoking and elevation data included geographic coordinates or precise place names for each cluster within that survey. In the absence of geographic coordinates for each cluster, we assigned data to the smallest available administrative areal unit in the survey (polygon) while accounting for the survey sample design<sup>49</sup>. Boundary information for these administrative units was obtained as shapefiles either directly from the surveys or by matching to shapefiles in the Global Administrative Unit Layers database<sup>42</sup> or the Database of Global Administrative Areas (GADM)<sup>50</sup>. In select cases, shapefiles provided by the survey administrator were used, or custom shapefiles were created based on survey documentation. Using methods from our previous works<sup>38</sup>, these areal data were resampled to point locations using a population-weighted sampling approach over the relevant areal unit with the number of locations set proportionally to the number of grid cells in the area and the total weights of all the resampled points summing to 1. In addition, some data sources did not contain hemoglobin concentrations and, instead, reported only the anemia severity category. These severity categories were used directly, whereas hemoglobin concentrations were adjusted and thresholded as described in the following section.

Select data sources were excluded for the following reasons: missing survey weights for areal data, missing sex or age variable, incomplete sampling (for example, only women aged 20–24 years measured) or untrustworthy data (as determined by the survey administrator or by inspection). Data availability plots for anemia by country, data type and year can be found in Supplementary Figs. 1–5.

**Hemoglobin adjustments and anemia severity.** For the purpose of defining anemia severity status, hemoglobin concentrations are often first adjusted for individual smoking status and residential elevation<sup>29</sup>. Many data sources provide some combination of raw hemoglobin, smoking-adjusted hemoglobin, elevation-adjusted hemoglobin and smoking- and elevation-adjusted hemoglobin concentrations. Wherever possible, this study started with the raw hemoglobin concentrations and performed both smoking and elevation adjustments, as suggested by the WHO. If only partially adjusted (either only smoking-adjusted or elevation-adjusted), we performed the second adjustment, and, if only completely adjusted hemoglobin concentrations were available, we used those. The elevation adjustments are shown in Supplementary Table 5, and the smoking adjustments are shown in Supplementary Table 6.

Once the hemoglobin concentrations had been doubly adjusted for smoking and elevation, they were then thresholded into non-anemic, mild anaemia, moderate anaemia or severe anaemia categories using the WHO definitions shown in Supplementary Table 7. Some data sources reported only the anemia severity categories, which were then used directly in the modeling stage. After classification into anemia severity categories, individual-level data observations were then collapsed to cluster-level totals for the number of WRA sampled and total number of WRA who were determined to be mildly, moderately or severely anemic.

**Temporal resolution.** We estimated the prevalence of mild, moderate and severe anemia annually from 2000 to 2018 using a model that allowed us to account

for data points measured across survey years and, as such, allows us to predict at monthly or finer temporal resolutions. We were limited, however, both computationally and by the temporal resolution of covariates and, thus, have produced annual estimates (Supplementary Table 8 and Supplementary Fig. 8).

**Spatial covariates.** A variety of socioeconomic and environmental variables were used to predict anemia. Where available, the finest spatio-temporal resolution of gridded datasets was used. These covariates were selected based on their potential to be predictive for anemia and the pathways to anemia, including certain nutritional deficiencies, according to literature review and plausible hypothesis as to their influence. Acquisition of temporally dynamic datasets, where possible, was prioritized to closely align with our observations and to predict the changing dynamics of the anemia severity indicators.

We used covariate-driven predictive models to leverage strength from locations with observations to the entire spatial-temporal domain. Several 5 × 5-km raster layers of putative socioeconomic and environmental correlates of anemia were compiled and used as covariates across the 82 LMICs in the modeling domain (Supplementary Table 8 and Supplementary Fig. 8). These covariates were selected based on their potential to be predictive for anemia and the pathways to anemia, including certain nutritional deficiencies, according to literature review and plausible hypothesis as to their influence. Acquisition of temporally dynamic datasets, where possible, was prioritized to closely align with our observations and to predict the changing dynamics of the anemia severity indicators. Of the 19 covariates included, 12 were temporally dynamic and were re-formatted as a mid-year estimate or synoptic mean for each year in the estimation period. These included average diurnal temperature range, average potential evapotranspiration, average daily mean rainfall (precipitation), outdoor air pollution (PM<sub>2.5</sub>), educational attainment in WRA (ages 15–49 years), enhanced vegetation index, tasseled cap brightness, prevalence of underweight (ages 0–5 years), Healthcare Access and Quality Index, fertility, urbanicity and population. The remaining seven covariate layers were static throughout the study period and were applied uniformly across all modeling years; these covariates included growing season length, irrigation, nutritional yield for vitamin A, nutritional yield for zinc, nutritional yield for iron, distance to rivers and lakes and travel time to nearest settlement with more than 50,000 inhabitants.

Travel time to nearest settlement, nutritional yield for vitamin A, nutritional yield for iron and nutritional yield for zinc were selected because of their potential to be predictive for anemia and the pathways to anemia. Fertility, malaria incidence, population, outdoor air pollution and prevalence of underweight were selected for inclusion in modeling owing to their correlation with a wide variety of health-related outcomes. Average daily mean temperature, average daily mean rainfall, irrigation, land cover, multi-source weighted-ensemble precipitation and tasseled cap brightness were selected for their correlation with a variety of crop yields. In addition, the stacking methodology used in this study boosts the predictive performance of individual covariates by leveraging non-linear and high-order interactions among the covariates and generally performs better when given a variety of covariates.

**Analysis. Geostatistical model.** To model the full distribution of possible indicators of anemia status—that is, all, mild, moderate and severe anemia—we used an ordinal modeling approach<sup>31</sup> to estimate the relative proportion of each indicator.

We implemented a continuation ratio model to estimate the prevalence of three categories: mild, moderate and severe. We first modeled the proportion of all anemia within a Bayesian hierarchical framework using logistic regression with a spatially and temporally explicit generalized linear mixed effects model. Second, we modeled the probability of being mildly anemic conditional on being anemic (that is, being mildly, moderately or severely anemic) using the same Bayesian modeling framework. Finally, we modeled the probability of being severely anemic conditional on being either moderately or severely anemic. The estimates from the two conditional models were combined with the all-anemia estimates to compute the marginal prevalence of mild, moderate and severe anemia.

For each modeling region, at each cluster,  $d$ , where  $d = 1, 2, \dots, n$ , and time  $t$ , where  $t = 2000, 2001, \dots, 2018$ , the prevalence of all anemia was modeled using the observed number of WRA in cluster  $d$  who were found to be anemic as a binomial count,  $C_d$ , among an observed sample of  $N_d$ :

$$C_d | p_{i(d),t(d)}, N_d \sim \text{Binomial}(p_{i(d),t(d)}, N_d) \forall \text{ observed clusters } d$$

$$\begin{aligned} \text{logit}(p_{i,t}) &= \beta_0 + \mathbf{X}_{i,t}\beta + Z_{i,t} + \epsilon_{ctr(i)} \\ &+ \epsilon_{i,t} + Z_{i,t} \forall i \in \text{spatial domain } \forall t \in \text{time domain} \end{aligned}$$

$$\sum_{h=1}^3 \beta_h = 1$$

$$\epsilon_{ctr} \sim \text{iid Normal}(0, \gamma^2)$$

$$\epsilon_{it} \sim \text{iid Normal}(0, \sigma^2)$$

$$Z \sim \text{GP}(0, \Sigma^{\text{space}} \otimes \Sigma^{\text{time}})$$

$$\Sigma^{\text{space}} = \frac{\omega^2}{\Gamma(\nu) 2^{\nu-1}} \times (\kappa D)^\nu \times K_\nu(\kappa D)$$

$$\Sigma_{j,k}^{\text{time}} = \rho^{|k-j|}$$

For indices  $d, i$  and  $t$ ,  $*$ (index) is the value of  $*$  at the index. The annual prevalence of all anemia,  $p_{i,t}$ , in spatial location  $i$ , in time  $t$ , was modeled as a linear combination of the three submodels (generalized additive model, boosted regression trees and lasso regression), rasterised covariate values,  $X_{i,t}$ , a correlated spatio-temporal random effect term  $Z_{i,t}$ , country random effects  $\epsilon_{ctr(i)}$ , with one unstructured country random effect fit for each country in the modeling region (Extended Data Fig. 3) and all  $\epsilon_{ctr}$  sharing a common variance parameter,  $\gamma^2$ , and an independent nugget random effect,  $\epsilon_{i,t}$ , with variance parameter  $\sigma^2$ . Coefficients  $\beta_h$  in the three submodels  $h \in 1, 2, 3$  represent their respective predictive weighting in the logit-link, whereas the joint structured process,  $Z_{i,t}$ , accounts for residual spatio-temporal autocorrelation among individual data points that remain after accounting for the predictive effect of the submodel covariates, the country-level random effect,  $\epsilon_{ctr(i)}$ , and the nugget,  $\epsilon_{i,t}$ . The spatio-temporal residual process,  $Z_{i,t}$ , was modeled as a three-dimensional Gaussian process in space–time centered at 0 and with a covariance matrix constructed from a Kronecker product of spatial and temporal covariance kernels. The spatial covariance,  $\Sigma^{\text{space}}$ , was modeled using an isotropic and stationary Matérn function<sup>52</sup> and the temporal covariance,  $\Sigma^{\text{time}}$ , as an annual autoregressive (AR1) function over the 19 years represented in the model. In the stationary Matérn function, the covariance between two spatial locations that are Euclidean distance  $D$  apart is a function of  $\Gamma$ , the gamma function,  $K_\nu$ , the modified Bessel function of the second kind of order  $\nu > 0$ ,  $\kappa > 0$ , a scaling parameter and  $\omega^2$ , the marginal variance. The scaling parameter,  $\kappa$ , is defined to be  $\kappa = \sqrt{8\nu}/\delta$ , where  $\delta$  is the range parameter (interpreted to be the approximate distance at which the correlation between two locations drops to 0.1), and  $\nu$  is a scaling constant, which is set to 2 rather than fit from the data. The number of rows and the number of columns of the spatial Matérn covariance matrix are both equal to the number of spatial mesh points for a given modeling region. The Matérn kernel is a practical and common choice that can flexibly model a wide variety of spatial surfaces and allows for fitting or selection of the smoothness of the surface, helping to avoid unrealistic over-smoothing<sup>52</sup>. For the temporal kernel, we chose to use an AR1 process owing to its stability, which aligns well with the observed relatively slow and smooth changes in anemia prevalence across time, and for its interpretability. In the AR1 function,  $\rho$  is the temporal correlation between adjacent time steps, taken to be single years in this study, and  $k$  and  $j$  are time steps. The number of rows and the number of columns of the AR1 covariance matrix are both equal to the number of temporal mesh points (19). The number of rows and the number of columns of the space–time covariance matrix,  $\Sigma^{\text{space}} \otimes \Sigma^{\text{time}}$ , for a given modeling region are equal (the number of spatial mesh points  $\times$  the number of temporal mesh points). Previous sensitivity analyses on these models showed these modeling choices to be generally quite robust<sup>37,53</sup>.

This approach leverages the residual correlation structure to more accurately predict prevalence estimates for locations with no data while also propagating the dependence in the data through to uncertainty estimates<sup>54</sup>. The posterior distributions were fit using computationally efficient and accurate approximations in R-INLA<sup>55</sup> (integrated nested Laplace approximation) with the stochastic partial differential equations (SPDE)<sup>56</sup> approximation to the spatio-temporal Gaussian process using R version 3.5.1. The SPDE approach using INLA was demonstrated elsewhere, including the estimation of health indicators, particulate air matter and population age structure<sup>56</sup>. Uncertainty intervals were generated from 1,000 draws (that is, statistically plausible candidate maps)<sup>57</sup> created from the posterior-estimated distributions of modeled parameters.

**Mesh construction.** We constructed the finite elements mesh for the SPDE approximation to the Gaussian process regression using a simplified polygon boundary (in which coastlines and complex boundaries were smoothed) for each of the regions within our model. We set the inner mesh triangle maximum edge length (the mesh size for areas over land) to be 0.75 degrees and the buffer maximum edge length (the mesh size for areas over the ocean) to be 5.0 degrees<sup>58</sup>. An example finite elements mesh constructed for eastern sub-Saharan Africa mesh can be found in Supplementary Fig. 7.

**Post-estimation.** To transform grid cell-level estimates into a range of information useful to a wide constituency of potential users, these estimates were aggregated at first and second administrative units specific to each country and at national levels<sup>59</sup>. Although the models can predict all locations covered by available raster covariates, all final model outputs for which land cover was classified as ‘barren or

sparsely vegetated’ on the basis of Moderate Resolution Imaging Spectroradiometer satellite data (2013) were masked<sup>59</sup>. Areas where the total population density was fewer than ten individuals per  $1 \times 1$ -km grid cell in 2015 were also masked in the final outputs. To compute the YLDs, we applied the corresponding disability weights from the GBD study<sup>30</sup> on prevalence estimates of the severity bins (mild, moderate and severe anemia) and summed to get the total YLDs for all anemia.

**Model validation.** Models were validated using spatially stratified five-fold out-of-sample cross-validation. To replicate real-world missingness in the datasets and to fairly assess model performance in areas far from observed data, acknowledging the spatial correlation inherent in the observation, holdout folds were created by combining sets of all data falling within first administrative-level units. Validation was performed by calculating bias (mean error), variance (root-mean-square error), 95% data coverage within prediction intervals and correlation between observed data and predictions. All validation metrics were calculated on the out-of-sample predictions from the five-fold cross-validation. All validation procedures and corresponding results are provided in Supplementary Tables 17–19 and Supplementary Figs. 20–22.

**In-sample metrics.** To assess the in-sample performance of our models and compare to national-level estimates produced by the GBD study, we generated a suite of diagnostic plots for anemia estimates in each of the regions and countries modeled. To explore residual error over space and time, absolute error (data minus predicted posterior mean estimates at the corresponding grid cells) was produced.

**Metrics of predictive validity.** To assess the predictive validity of our estimates, we validated our models using spatially stratified five-fold out-of-sample cross-validation<sup>60</sup>. To construct each spatial fold, we used a modified bi-tree algorithm to spatially aggregate data points. This algorithm recursively partitions two-dimensional space, alternating between horizontal and vertical splits on the weighted data sample size medians, until the data contained within each spatial partition are of a similar sample size. The depth of recursive partitioning is constrained by the target sample size within a partition and the minimum number of clusters or pseudo-clusters allowed within each spatial partition (in this case, a minimum sample size of 500 was used). These spatial partitions are then allocated to one of five folds for cross-validation. For validation, each geostatistical model was run five times, each time holding out data from one of the folds, generating a set of out-of-sample predictions for the held-out data. A full suite of out-of-sample predictions over the entire dataset was generated by combining the out-of-sample predictions from the five cross-validation runs.

Using these out-of-sample predictions, we then calculated mean error (or bias), root-mean-squared error (RMSE, which summarizes total variance), coefficient of variation (defined to be the standard deviation divided by the mean and multiplied by 100, which is a measure of relative variability) and 95% coverage of our predictive intervals (the proportion of observed out-of-sample data that fall within our predicted 95% credible intervals) aggregated up to different administrative levels (levels 0, 1 and 2) as defined by the GADM<sup>61</sup>. Administrative level 0 (admin 0) borders correspond to national boundaries; administrative level 1 (admin 1) borders generally correspond to regions, provinces or state-level boundaries within a country; and administrative level 2 (admin 2) borders correspond to the next finer subdivision, often districts, within regions. These metrics are summarized in Supplementary Tables 13–15 and Supplementary Figs. 15–17 and are calculated across all regions. Included in the sample tables for comparison are the same metrics calculated on in-sample predictions.

**Sensitivity analysis.** We ran four five-fold cross-validation holdout in-sample experiments, using different combinations of covariates and random effects:

1. Raw covariates + Gaussian process:  $\text{logit}(p_i) = \beta_0 + X_i \beta_{\text{raw}} + \epsilon_{GP_i} + \epsilon_i$
2. Raw covariates:  $\text{logit}(p_i) = \beta_0 + X_i \beta_{\text{raw}} + \epsilon_i$
3. Stacking predictions as covariates:  $\text{logit}(p_i) = \beta_0 + X_i \beta_{\text{stack}} + \epsilon_i$
4. Stacking covariates + Gaussian process (standard model):  
 $\text{logit}(p_i) = \beta_0 + X_i \beta_{\text{stack}} + \epsilon_{GP_i} + \epsilon_i$

The summary error measures for all models are shown in Supplementary Figs. 20 and 21 to demonstrate how adding stackers or the Gaussian process individually change predictive capacity on administrative level 1 and 2, respectively. Across the two levels of aggregation and all four validation metrics, the models with a Gaussian process outperformed those without, as they had smaller RMSE and greater correlation. For the standard model, which used both the stacking covariates and the Gaussian process, the in-sample RMSE and correlation were 0.053 and 0.078 and 0.87 and 0.77 at administrative levels 1 and 2, respectively. For the raw covariates model with the Gaussian process, RMSE = 0.069 and 0.084, and the correlation = 0.71 and 0.63; for the model that used raw covariates only, RMSE = 0.066 and 0.091, and the correlation = 0.55 and 0.43; and for the stacked covariates model, RMSE = 0.056 and 0.079, and the correlation = 0.85 and 0.75, at administrative levels 1 and 2, respectively.

**Projections.** To compare our estimated rates of improvement in all-anemia prevalence over the 19-year period across different locations, and to assess if



locations are on track to meet the WHO GNT for anemia given historical rates of improvement, we performed a simple projection using estimated AROCs applied to the final year of our estimates. Both AROCs and projections were calculated at the draw level to construct uncertainty estimates for both.

For all-anemia prevalence, we calculated AROCs at each administrative-level unit ( $a$ ) by calculating the AROC between each pair of adjacent years,  $t$ :

$$AROC_{a,t} = \text{logit} \left( \frac{p_{a,t}}{p_{a,t-1}} \right)$$

We then calculated a weighted AROC for all-anemia by taking a weighted average across the years, where more recent AROCs were given more weight in the average. We defined the weights to be:

$$W_t = \frac{(t - 2000)^\gamma}{\sum_{2001}^{2018} (t - 2000)^\gamma},$$

where  $\gamma$  may be chosen to give varying amounts of weight across the years. Using the weights and the AROCs between consecutive years, the average AROC across the duration of the study was calculated:

$$AROC_a = \left( \sum_{2001}^{2018} W_t * AROC_{a,t} \right)$$

Finally, we calculated the projections (*Proj*) by applying the 7 years of the AROC (from 2018 to 2025) to our mean 2018 prevalence estimates. The projection was performed in logit-space (consistent with the AROC calculation) to ensure that the projected estimates range between 0 and 1:

$$Proj_{a,2025} = \text{logit}^{-1} (\text{logit} (p_{a,2018}) + AROC_a \times 7).$$

This projection scheme is analogous to the methods used in the GBD 2017 measurement of progress and projected attainment of health-related SDGs<sup>18</sup>. The exponential power in the weighting scheme was chosen to match that used by the GBD study, which selects this parameter using an out-of-sample predictive validation framework. Our projections assume that areas will sustain the current AROC, and the precision of the AROC estimates is dependent on this assumption and the uncertainty from the all-anemia annual prevalence estimates.

**Post-estimation calibration to national and subnational estimates.** To leverage national-level data that were included in GBD 2017 (ref.<sup>18</sup>) but were outside the scope of our current geospatial modeling framework, and to ensure alignment between this study's estimates and GBD 2017 estimates, we performed a post hoc calibration to each of our 1,000 candidate maps. For each posterior draw, we calculated population-weighted grid cell aggregations at the level of GBD estimates (at national or subnational level) and compared these estimates in each year to the analogous and available GBD 2017 estimates from 2000 to 2017. We defined the raking factor to be the ratio between the GBD 2017 estimates and our current estimates and linearly interpolated raking factors in each country between the available years. Finally, we multiplied each of our grid cells in a country-year by its associated raking factor. This ensures alignment between our geospatial estimates and GBD 2017 estimates while preserving our estimated within-country geospatial and temporal variation.

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

## Data availability

The findings of this study are supported by data available in public online repositories, data publicly available upon reasonable request of the data provider and data not publicly available owing to restrictions by the data provider. Non-publicly available data were used under licence for the current study but might be available from the authors upon reasonable request and with permission of the data provider. A detailed table of data sources and availability can be found in Supplementary Section 2. The full list of input data sources and output of the analyses is publicly available in the Global Health Data Exchange (<http://ghdx.healthdata.org/record/ihme-data/global-anemia-prevalence-geospatial-estimates-2000-2019>) and can further be explored via customized data visualization tools (<https://vizhub.healthdata.org/lbd/anemia>).

Administrative boundaries were retrieved from the Database of Global Administrative Areas<sup>50</sup>. Land cover was retrieved from the online Data Pool, courtesy of the NASA EOSDIS Land Processes Distributed Active Archive Center, USGS/Earth Resources Observation and Science Center<sup>43</sup>. Lakes were retrieved from the Global Lakes and Wetlands Database<sup>45</sup>, courtesy of the World Wildlife Fund and the Center for Environmental Systems Research at the University of Kassel<sup>44</sup>. Populations were retrieved from WorldPop<sup>46,47</sup>.

## Code availability

This study follows the Guidelines for Accurate and Transparent Health Estimates Reporting (GATHER; Supplementary Table 1). All code used for these

analyses is publicly available at <http://ghdx.healthdata.org/record/ihme-data/global-anemia-prevalence-geospatial-estimates-2000-2019> and <https://github.com/ihmeuw/lbd/tree/anemia-lmic-2021>.

## References

- Lumley, T. Analysis of complex survey samples. *J. Stat. Softw.* **9**, 1–19 (2004).
- Global Administrative Areas (GADM). GADM maps and data. <http://www.gadm.org>
- Ananth, C. V. & Kleinbaum, D. G. Regression models for ordinal responses: a review of methods and applications. *Int. J. Epidemiol.* **26**, 1323–1333 (1997).
- Stein, M. L. *Interpolation of Spatial Data* (Springer, 1999).
- Dwyer-Lindgren, L. et al. Mapping HIV prevalence in sub-Saharan Africa between 2000 and 2017. *Nature* **570**, 189–193 (2019).
- Hotez, P. & Ribeiro, P. *Model-based Geostatistics* (Springer, 2007).
- Rue, H., Martino, S. & Chopin, N. Approximate Bayesian inference for latent Gaussian models by using integrated nested Laplace approximations. *J. R. Stat. Soc. Ser. B (Methodol.)* **71**, 319–392 (2009).
- Lindgren, F., Rue, H. & Lindström, J. An explicit link between Gaussian fields and Gaussian Markov random fields: the stochastic partial differential equation approach. *J. R. Stat. Soc. Ser. B (Methodol.)* **73**, 423–498 (2011).
- Patil, A. P., Gething, P. W., Piel, F. B. & Hay, S. I. Bayesian geostatistics in health cartography: the perspective of malaria. *Trends Parasitol.* **27**, 246–253 (2011).
- Fienberg, S. E. *The Analysis of Cross-Classified Categorical Data* (Springer, 2007).
- Scharlemann, J. P. W. et al. Global data for ecology and epidemiology: a novel algorithm for temporal Fourier processing MODIS data. *PLoS ONE* **3**, e1408 (2008).
- Roberts, D. R. et al. Cross-validation strategies for data with temporal, spatial, hierarchical, or phylogenetic structure. *Ecography* <https://doi.org/10.1111/ecog.02881> (2016).

## Acknowledgements

This work was primarily supported by grant OPP1132415 from the Bill & Melinda Gates Foundation. Lucas Guimarães Abreu acknowledges support from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) – Código de Financiamento 001, Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) (404710/2018-2 and 310797/2019-5), Fundação de Amparo à Pesquisa de Minas Gerais (FAPEMIG) and Pró-Reitoria de Pesquisa (PRPq) of Universidade Federal de Minas Gerais. Olatunji Adetokunboh acknowledges the Department of Science and Innovation and National Research Foundation for its support. Syed Aljunid acknowledges the Department of Health Policy and Management, Faculty of Public Health, Kuwait University and International Centre for Casemix and Clinical Coding, Faculty of Medicine, National University of Malaysia for the approval and support to participate in this research project. Alaa Badawi acknowledges support by the Public Health Agency of Canada. Josip Car acknowledges their post at Imperial College London, which is supported by the NIHR NW London Applied Research Collaboration. Felix Carvalho acknowledges UID/MULTI/04378/2019 and UID/QUI/50006/2019 support, with funding from FCT/MCTES through national funds. Vera Marisa Costa acknowledges her grant (SFRH/BHD/110001/2015), received by Portuguese national funds through Fundação para a Ciência e Tecnologia (FCT), IP, under the Norma Transitória DL57/2016/CP1334/CT006. Jan-Walter De Neve acknowledges support by the Alexander von Humboldt Foundation. Kebede Deribe acknowledges support by the Wellcome Trust (grant no. 201900/Z/16/Z) as part of his International Intermediate Fellowship. Sagnik Dey acknowledges support from IIT Delhi for the Institute Chair position. Marcel Ausloos, Adrian Pana and Claudiu Herteliu are partially supported by a grant from the Romanian National Authority for Scientific Research and Innovation, CNDS-UEFISCDI, project number PN-III-P4-ID-PCCF-2016-0084. Claudiu Herteliu is partially supported by a grant co-funded by the European Fund for Regional Development through the Operational Program for Competitiveness, project ID P\_40\_382. Claudiu Herteliu and Adrian Pana are partially supported by a grant from the Romanian National Authority for Scientific Research and Innovation, CNDS-UEFISCDI, project number PN-III-P2-2.1-SOL-2020-2-0351. Praveen Hoogar wholeheartedly thanks the Centre for Bio Cultural Studies (CBICS), Directorate of Research, Manipal Academy of Higher Education (MAHE), Manipal. Sheikh Mohammed Shariful Islam is funded by a Fellowship from the National Heart Foundation of Australia and NHMRC. Oommen John is the recipient of an UIPA scholarship, UNSW, Sydney. Md. Nuruzzaman Khan acknowledges Jatiya Kabi Kazi Nazrul Islam University, Bangladesh. Yun Jin Kim acknowledges support by the Research Management Centre, Xiamen University Malaysia (grant no. XMUMRF/2020-C6/ITM/0004). Kewal Krishan acknowledges support by a DST PURSE grant and the UGC Centre of Advanced Study (CAS II) awarded to the Department of Anthropology, Panjab University. Ben Lacey acknowledges support from the NIHR Oxford Biomedical Research Centre and the BHF Centre of Research Excellence, Oxford. Iván Landires is member of the Sistema Nacional de Investigación (SNI), which is supported by the Secretaría Nacional de Ciencia, Tecnología e Innovación (SENACYT), Panamá. Alberto Ortiz acknowledges their research, which is supported by FRIAT, ISCIII FEDER funds RETIC REDINREN RD016/0009. George Patton acknowledges support from an NHMRC research

fellowship. Maarten J. Postma reports various grants and honoraria from public and private partners and shareholdership in two health economics consultancies. Rajesh Kumar Rai received financial support from the West Bengal State Department of Health and Family Welfare, India (memo no. 114-P&B/ HFW-27011/114/2019-NHM SEC). Milena Santric-Milicevic acknowledges the support received from the Ministry of Education, Science and Technological Development of the Republic of Serbia (contract no. 175087). Feng Sha acknowledges support from the Shenzhen Science and Technology Program (grant no. KQTD20190929172835662). Aziz Sheikh acknowledges Health Data Research UK. Adithi Shetty acknowledges Kasturba Medical College, Mangalore and Manipal Academy of Higher Education for the support and encouragement. B. Suresh Kumar Shetty acknowledges Kasturba Medical College, Mangalore and Manipal Academy of Higher Education, Manipal for the encouragement and support provided. Mohammad Reza Sobhiyeh acknowledges the clinical research development center of Imam Reza Hospital Kermanshah University of Medical Sciences for their wise advice. Riaz Uddin is supported by the Alfred Deakin Postdoctoral Research Fellowship. Charles Shey Wiysong's work is supported by the South African Medical Research Council. Sojib Bin Zaman received a scholarship from the Australian Government Research Training Program in support of his academic career. Yunquan Zhang was supported by the Key Research Center for Humanities and Social Sciences in Hubei Province (Hubei University of Medicine) (grant no. 2020ZD001).

## Author contributions

S.I.H. and N.J.K. conceived and planned the study. S.B.E., A.L.A., D.L. and K.M.D. identified and obtained data for analysis. S.B.E., A.L.A., D.L. and K.M.D. extracted, processed and geo-positioned the data. D.K.K. carried out the statistical analyses with input from A.O.-Z. and A.L.A. A.O.-Z., N.J.H., M.L.C., M.A.C., J.F.M., A.D., L.P.W., J.D.V., K.E.W., R.C.R. and L.D.-L. provided input on the methods. D.K.K., L.E.S., I.L. and A.C. prepared the figures and tables. M.F.S. served as project manager for the study. D.K.K., L.E.S. and A.O.-Z. wrote the first draft of the manuscript, and all authors contributed to subsequent revisions. All authors provided intellectual input into aspects of this study, specifically as below. Managing the estimation or publications process: Damaris Kinyoki, Aaron Osgood-Zimmerman and Megan Schipp. Writing the first draft of the manuscript: Damaris Kinyoki, Aaron Osgood-Zimmerman, Lauren Schaeffer and Megan Schipp. Primary responsibility for this manuscript focused on applying analytical methods to produce estimates: Damaris Kinyoki, Aaron Osgood-Zimmerman and Natalia V. Bhattacharjee. Primary responsibility for this manuscript focused on seeking, cataloguing, extracting or cleaning data and designing or coding figures and tables: Lauren Schaeffer, Alice Lazzar-Atwood, Dan Lu, Samuel B. Ewald, Katie Donkers, Ian Louterneau and Michael Collison. Providing data or critical feedback on data sources: Damaris Kinyoki, Samuel B. Ewald, Ian Louterneau, Megan Schipp, Mitra Abbasifard, Hedayat Abbastabar, Foad Abd-Allah, Ahmed Abdelalim, Amir Abdoli, Hassan Abolhassani, Ahmed Abualhasan, Abdelrahman Abushouk, Maryam Adabi, Oladimeji Adebayo, Victor Adekanmbi, Olatunji Adetokunboh, Daniel Adeyinka, Shailesh Advani, Sohail Ahmad, Tauseef Ahmad, Sepideh Ahmadi, Muktar Ahmed, Miloud Taik Eddine Aichour, Budi Aji, Oluwaseun Akinyemi, Addis Akililu, Chisom Akunna, Jacqueline Alcalde-Rabalan, Sheikh Alif, Hesam Alizade, Syed Aljunid, Amir Almasi-Hashiani, Nelson Alvis-Guzman, Saeed Amini, Nahla Anber, Tudorel Andrei, Masresha Anegago, Mina Anjomshoa, Fereshteh Ansari, Ernoiz Antriyandarti, Davoud Anvari, Muhammad Aqeel, Salal Arabloo, Morteza Arab-Zozani, Olatunde Aremu, Mulusew Asemahagn, Seyyed Shamsadin Athari, Seyyede Masoume Athari, Marcel Ausloos, Nefsu Awoke, Beatriz Paulina Ayala Quintanilla, Getinet Anyo, Yared Aynalem, Alaa Badawi, Mohammad Amin Bahrami, Palash Banik, Miguel Barboza, Sanjay Basu, Gholamreza Bazmandegan, Neeraj Bedi, Tariku Tesfaye Bekuma, Suraj Bhattarai, Boris Birkhov, Somayeh Bohlouli, Mahdi Bohlouli, Archith Boloor, Shiva Borzouei, Nicola Bragazzi, Dejana Braithwaite, Luis Cámera, Luis Cámera, Joao Mauricio Castaldelli-Maia, Carlos Castañeda-Orjuela, Franz Castro, Souranshu Chatterjee, Vijay Kumar Chattu, Simiao Chen, Vera Costa, Lalit Dandona, Rakhi Dandona, Rajat Das Gupta, Aditya Dash, Kairat Davletov, Kebede Deribe, Meghnath Dhimal, Govinda Dhungana, Mostafa Dianatinasab, Hoa Do, Leila Doshmangir, Andre Duraes, Maysaa El Sayed Zaki, Rajesh Elayedath, Teshome Elema, Babak Eshtrati, Khalil Eskandari, Emerito Jose Faraon, Mohammad Fareed, Farshad Farzadfar, Abidemi Fasanmi, Berhanu Feleke, Takeshi Fukumoto, Mohamed Gad, Abhay Gaidhane, Reta Gabya, Birhan Gebregiorgis, Leake Gebremeskell, Yilma Geramo, Lemma Getacher, Keyghobad Ghadiri, Fatemeh Ghaffarifar, Ahmad Ghashghhaee, Nermin Ghith, Ayman Grada, Nachiket Gudi, Arvin Haj-Mirzaian, Ahmed Hasaballah, Syed Shahzad Hasan, Abdiwahab Hashi, Soheil Hassanipour, Hadi Hassankhani, Mohamed Hegazy, Reza Heidari-Soureshjani, Claudiu Herteliu, Praveen Hoogar, Mehdi Hosseinzadeh, Mowafa Housseh, Syed Hussain, Usman Iqbal, Sheikh Mohammed Shariful Islam, Vardhmaan Jain, Mihajlo Jakovljevic, Amir Jalali, Tahereh Javaheri, Oommen John, Kimberly Johnson, Jost Jonas, Farahnaz Joukar, Jacek Jozwiak, Zubair Kabir, Leila Kalanesh, Rohollah Kalhor, Ashwin Kamath, Zahra Kamiab, Umsh Kapil, Salal Eddin Karimi, Ayele Semachew Kasa, Gbenga Kayode, Bayew Kelkay, Nauman Khalid, Maseer Khan, Md. Nuruzzaman Khan, Khaled Khatib, Amir Khater, Mona Khater, Abdullah Khoja, Jagdish Khubchandani, Neda Kianipour, Young-Eun Kim, Yun Jin Kim, Adnan Kisa, Sezer Kisa, Soewarta Kosen, Parvaiz Koul, Kewal Krishan, Barthelemy Kuate Defo, G. Anil Kumar, Pushpendra Kumar, Om Kurmi, Dian Kusuma, Deepesh Lad, Dharmesh Lal, Huong Lan Nguyen, Anders Larsson, Savita Lasardo, Savita Lasrado, Kate Legrand, Chi Linh Hoang, Xuefeng Liu, Jaifred Christian Lopez, Hassan Magdy Abd El Razek, Muhammed Magdy Abd El Razek, D. R. Mahadeshwara Prasad, Narayan Mahotra, Shokofeh Maleki, Reza Malekzadeh, Deborah Malta, Deborah Malta,

Fariborz Mansour-Ghanaei, Borhan Mansouri, Francisco Martins-Melo, Benjamin Mayala, Medhin Mehari, Man Mohan Mehndiratta, Entezar Mehrabi Nasab, Mulugeta Melku, Walter Mendoza, Ritesh Menezes, Endalkachew Mengesha, Meresa Mengesha, Workua Metekiya, Erkin Mirrakhimov, Hamed Mirzaei, Babak Moazan, Masoud Moghadaszadeh, Dara Mohammad, Naser Mohammad Gholi Mezerji, Abdollah Mohammadian-Hafshejani, Ammas Mohammed, Hayat Mohammed, Salahuddin Mohammed, Shafiu Mohammed, Ali Mokdad, Masoud Moradi, Maziar Moradi-Lakeh, Seyyed Meysam Mousavi, Getaneh Mulu, Mehnaz Munir, Ghulam Mustafa, Mehdi Naderi, Ahamarshan Nagarajan, Shankar Prasad Nagaraji, Bruno Nascimento, Javad Nazari, Ionut Negoii, Ruxandra Negoii, Georges Nguefack-Tsague, Josephine Ngunjiri, Cuong Nguyen, Yeshambel Nigatu, Amin Reza Nikpoor, Chukwudi Nnaji, Vuong Nong, Jean Jacques Noubia, Bogdan Oancea, Felix Ogbo, Andrew Olagunju, Bolajoko Olusanya, Jacob Olusanya, Ahmed Omar Bali, Obinna Onwujekwe, Mayowa Owolabi, Mahesh P A, Jagadish Rao Padubidri, Keyvan Pakshir, Adrian Pana, Songhomitra Panda-Jonas, Anamika Pandey, Seithikurippu Pandi-Perumal, Deepak Kumar Pasupala, Urwish Patel, Ashish Pathak, Jeevan Pereira, Julia Pescarini, Brandon Pickering, Khem Pokhrel, Maarten Postma, Hadi Pourjafar, Sergio Prada, Hai Quang Pham, Zahiruddin Quazi Syed, Navid Rabiee, Fakher Rahim, Amir Masoud Rahmani, Aashish Rajesh, Kiana Ramezanzadeh, Chhabi Ranabhat, Sowmya J. Rao, Lal Rawal, Reza Rawassizadeh, Bhageerathy Reshmi, Nima Rezaei, Seyed Mohammad Riahi, Jennifer Rickard, Leonardo Roever, Godfrey Rweggerera, Siamak Sabour, Ehsan Sadeghi, Rajesh Sagar, S. Mohammad Sajadi, Nasir Salam, Milena Santric-Milicevic, Sivan Saraswathy, Arash Sarveezad, Brijesh Sathian, Deepak Saxena, David Schwebel, Debarka Sengupta, Subramanian Senthilkumaran, Sadaf Sepanlou, Allen Seylani, Feng Sha, Omid Shafaat, Saeed Shahabi, Masood Shaikh, Mohammed Shaka, Mohammadbagher Shamsi, Morteza Shamsizadeh, Mohammed Shannawaz, Amrollah Sharifi, Adithi Shetty, B. Suresh Shetty, Wondimeneh Shiferaw, Jae Il Shin, Soraya Siabani, Valentin Skryabin, Anna Skryabina, Mohammad Reza Sobhiyeh, Amin Soheili, Emma Spurlock, Emma Spurlock, Chandrashekhar Sreeramareddy, Agus Sudaryanto, Rafael Tabarés-Seisdedos, Amir Taherkhani, Zemenu Tamir, Animit Tamiru, Hirut Teame, Nihal Thomas, Asres Tilahun, Marcos Tovani-Palone, Khanh Tran, Bach Tran Xuan, Rajnish Tripathi, Phuung Truong, Riaz Uddin, Anayat Ullah, Bhaskaran Unnikrishnan, Era Upadhyay, Alireza Vakilian, Pascual Valdez, Pascual Ruben Valdez, Yasser Vasseghian, Bay Vo, Yohannes Wado, Yasir Waheed, Yafeng Wang, Girmay Weldesamuel, Tawewat Wiangkham, Charles Wiysong, Ali Yadollahpour, Mingyou Yang, Sanni Yaya, Alex Yeshaneh, Yordanos Yeshitila, Mekdes Yilma, Melissa Young, Abdilahi Yousuf, Chuanhua Yu, Syed Saoud Zaidi, Josefinia Zakzuk, Mohammad Zamani, Alireza Zangeneh, Mikhail Zastrozhin, Anastasia Zastrozhina Dejene Zewdie and Arash Ziapour. Developing methods or computational machinery: Damaris Kinyoki, Aaron Osgood-Zimmerman, Muktar Ahmed, Hesam Alizade, Amir Almasi-Hashiani, Nahla Anber, Masresha Anegago, Davoud Anvari, Mulusew Asemahagn, Nefsu Awoke, Yared Aynalem, Mohammad Amin Bahrami, Natalia V. Bhattacharjee, Somayeh Bohlouli, Shiva Borzouei, Farah Daoud, Mostafa Dianatinasab, Lucas Earl, Khalil Eskandari, Reza Heidari-Soureshjani, Nathaniel Henry, Mowafa Househ, Amir Khater, Neda Kianipour, Young-Eun Kim, Adnan Kisa, Borhan Mansouri, Fereshteh Mehri, Masoud Moghadaszadeh, Salahuddin Mohammed, Ali Mokdad, Mohsen Naghavi, Rajan Nikbakhsh, Chhabi Ranabhat, Seyed Mohammad Riahi, Alyssa Sbarra, Allen Seylani, Omid Shafaat, Emma Spurlock, Hirut Teame, Rajnish Tripathi, Era Upadhyay, Yasser Vasseghian, Syed Saoud Zaidi, Mikhail Zastrozhin, Anastasia Zastrozhina and Arash Ziapour. Providing critical feedback on methods or results: Damaris Kinyoki, Lauren Schaeffer, Ian Louterneau, Megan Schipp, Amanuel Abajobir, Nooshin Abbasi, Sima Abbasi, Sherief Abd-Elasalim, Ibrahim Abdollahpour, Aidin Abedi, Biju Abraham, Lucas Abreu, Michael Abrigo, Eman Abu-Gharbieh, Manfred Accrombessi, Adeyinka Adegbosin, Davoud Adham, Pradyumna Agasthi, Mohammad Aghaali, Keivan Ahmadi, Ziyad Al-Aly, Turki Alanzi, Aynalem Alemu, Biresaw Alemu, Robert Alhassan, Wahid Alipour, Hesham Al-Mekhlafi, Rajaa Al-Raddadi, Fatemeh Amiri, Dickson Amugsi, Robert Ancuceanu, Fereshteh Ansari, Alireza Ansari-Moghaddam, Zelalem Anteneh, Habtamu Areri, Al Artaman, Mengistu Ashebir, Maha Atout, Martin Ayanore, Muluken Ayza, Abbas Azadmehr, Darshan B. Tesleem Babalola, Ashish Badiye, Mohan Bairwa, Adhanom Baraki, Huda Basaleem, Mohsen Bayati, Bayisa Baye, Michelle Bell, Abadi Berhe, Kidanemariam Berhe, Kidanemariam Berhie, Dinesh Bhandari, Nikha Bhardwaj, Pankaj Bhardwaj, Kritika Bhattacharyya, Zulfiqar Bhutta, Ali Bijani, Antonio Biondi, Minyichil Birhanu, Andre Brunoni, Sharath Burugina Nagaraja, Zahid Butt, Florentino Luciano Caetano Dos Santos, Rosario Cárdenas, Muge Cevik, Wagaye Chanie, Jaykaran Charan, Ken Chin, Mohiuddin Hsanul Kabir Chowdhury, Beriuhun Dachew, Henok Dagne, Saad Dahlawi, Haijiang Dai, Hangcheng Dai, Jai Das, Claudio Davila-Cervantes, Jan-Walter De Neve, Farah Deeba, Assefa Desalew, Getenet Dessie, Sagnik Dey, Daniel Diaz, Shirin Djalalinia, Fariba Dorostkar, Bereket Duko, Hisham Edinur, Iman El Sayed, Hala Elhabashy, Aisha Elsharkawy, Yasser El-Sherbiny, Daniel Endalew, Sharareh Eskandarieh, Ibtihal Fadhil, Pawan Faris, Medhat Farwati, Nazir Fattahi, Valery Feigin, Seyed-Mohammad Fereshtehnejad, Nataliya Foigt, Artem Fomenkov, Masoud Foroutan, Joel Francis, Richard Franklin, Biniyam Geberemariam, Hadush Gebremariam, Gebreamlak Gebremeskell, Assefa Ayalew Gebreslassie, Hailay Gesesew, Bradford Gessner, Mansour Ghafourifar, Mahsa Ghajarzadeh, Farhad Ghamari, Syed Amir Gilani, Tiffany Gill, Myron Godinho, Philimon Gona, Davide Guido, Rashid Guled, Yuming Guo, Rachita Gupta, Randah Hamadeh, Demelash Woldeyohannes Handiso, Asif Hanif, Arief Hargono, Md. Mehdi Hassan, Maryam Hashemian, Shoaib Hassan, Khezar Hayat, Fatemeh Heydarpour, Susan Heydarpour, Hagos Hidru, Ramesh Holla, Sung Hwi Hong, Seyyed Nasrollah Hosseini, Mihaela Hostiuc, Sorin Hostiuc, Peter Hotez, Tanvir



Ritesh Menezes, Tuomo Meretoja, Shabir Mir, Babak Moazen, Masoud Moghadaszadeh, Dara Mohammad, Yousef Mohammad, Abdollah Mohammadian-Hafshejani, Reza Mohammadpourhodki, Jemal Mohammed, Salahuddin Mohammed, Shafiu Mohammed, Mohammad Mohseni Bandpei, Ali Mokdad, Lorenzo Monasta, Maziar Moradi-Lakeh, Paula Moraga, Abbas Mosapour, Amin Mousavi Khaneghah, Mehnaz Munir, Ghulam Mustafa, Ashraf Nabhan, Ahmarshan Nagarajan, Shankar Prasad Nagaraju, Mohsen Naghavi, Mukhammad David Naimzada, Vinay Nangia, Jobert Richie Nansseu, Bruno Nascimento, Smitha Nayak, Vinod Nayak, Javad Nazari, Ionut Negoii, Ruxandra Negoii, Henok Netsere, Georges Nguefack-Tsague, Josephine Ngunjiri, Cuong Nguyen, Yeshambel Nigatu, Rajan Nikbaksh, Amin Reza Nikpoor, Vuong Nong, Jean Jacques Noubiap, Virginia Nuñez-Samudio, Vincent Nwatah, Bogdan Oancea, Felix Ogbo, Onome Oghenetega, In-Hwan Oh, Seyede Momeneh Ohammadi, Morteza Oladnabi, Andrew Olagunju, Bolajoko Olusanya, Jacob Olusanya, Muktar Omer, Abidemi Omonisi, Obinna Onwujekwe, Alberto Ortiz, Eduardo Ortiz-Panozo, Nikita Otstavnov, Stanislav Otstavnov, Mayowa Owolabi, Mahesh P A, Jagadish Rao Padubidri, Adrian Pana, Songhomitra Panda-Jonas, Helena Pangaribuan, Urvish Patel, Hamidreza Pazoki Toroudi, Saeed Pirouzpanah, Khem Pokhrel, Maarten Postma, Sergio Prada, Hai Quang Pham, Zahiruddin Quazi Syed, Navid Rabiee, Fakher Rahim, Mohammad Hifz Ur Rahman, Pradhun Ram, Chhabi Ranabhat, Satish Rao, Sowmya J. Rao, Lal Rawal, Wasiq Rawasia, Lemma Regassa, Bhageerathy Reshmi, Nima Rezaei, Seyed Mohammad Riahi, Ana Isabel Ribeiro, Daniela Ribeiro, Jennifer Rickard, Leonardo Roever, Luca Ronfani, Morteza Rostamian, Susan Rumisha, Godfrey Rweggera, Siamak Sabour, Rajesh Sagar, Amirhossein Sahebkar, Mohammad Ali Sahraian, Nasir Salam, Marwa Salem, Hossein Samadi Kafil, Itamar Santos, Milena Santric-Milicevic, Arash Sarveazad, Deepak Saxena, David Schwebel, Subramanian Senthilkumaran, Saeed Shahabi, Izza Shahid, Masood Shaikh, Mohammed Shaka, Mahdi Shamali, Mehran Shams-Beyranvand, Morteza Shamsizadeh, Amrollah Sharifi, Aziz Sheikh, Mika Shigematsu, Jae Il Shin, Reza Shirkoohi, Velizar Shivarov, Sudeep Siddappa Malleshappa, Tariq Jamal Siddiqi, Negussie Sidemo, Surya Singh, Valentin Skryabin, Anna Skryabina, Muluken Sorrie, Chandrashekar Sreeramareddy, Mu'awiyyah Sufiyan, Iyad Sultan, Takahiro Tabuchi, Eyayou Tadesse, Zemenu Tamir, Animit Tamiru, Hirut Teame, Yohannes Tekalegn, Mohamad-Hani Temsah, Kavumpurathu Thankappan, Nihal Thomas, Maria Titova, Marcos Tovani-Palone, Bach Tran Xuan, Rajnish Tripathi, Jaya Tripathy, Riaz Uddin, Bhaskaran Unnikrishnan, Era Upadhyay, Muhammad Shariq Usman, Marco Vacante, Sahel Valadan Tahbaz, Yasser Vasseghian, Madhur Verma, Francesco Violante, Yasir Waheed, Yafeng Wang, Kinley Wangdi, Nuwan Wickramasinghe, Charles Wiysonge, Tewodros Wonde, Ai-Min Wu, Chenkai Wu, Seyed Hossein Yahyazadeh Jabbari, Sanni Yaya, Vahid Yazdi-Feyzabadi, Tomas Yeheyis, Alex Yeshaneh, Yigizie Yeshaw, Yordanos Yeshitila, Mekdes Yilma, Hebat-Allah Yousof, Syed Saoud Zaidi, Sojib Bin Zaman, Mohammad Zamani, Maryam Zamanian, Alireza Zandifar, Mikhail Zastrozhin, Anastasia Zastrozhina, Arash Ziapour and Simon I. Hay. Managing the overall research enterprise: Damaris Kinyoki, Aubrey J. Cook, Lalit Dandona, Deborah Malta, Ali Mokdad, Mohsen Naghavi, George Patton, Benn Sartorius, Andrea Werdecker and Simon I. Hay.

### Competing interests

This study was funded by the Bill & Melinda Gates Foundation. Co-authors employed by the Bill & Melinda Gates Foundation provided feedback on initial maps and drafts of this manuscript. Otherwise, the funders of the study had no role in study design, data collection, data analysis, data interpretation or writing of the final report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication. R.A. received consultancy/speaker fees from UCB, Sandoz, Abbvie, Zentiva, Teva, Laropharm, CEGEDIM,

Angelini, Biessen Pharma, Hofigal, AstraZeneca and Stada. Dr. Bell reports grants from the Wellcome Trust Foundation, grants from the NIH, grants from the Environmental Protection Agency, personal fees from the University of Montana, other from the NIH and grants from the Yale Climate Change and Health Center, all outside of the submitted work. Dr. Gessner reports employment from Pfizer Vaccines, outside of the submitted work. Dr. Islam reports grants from the National Heart Foundation of Australia and grants from the NHMRC, outside of the submitted work. Dr. Jozwiak reports personal fees from Amgen, personal fees from Alab Laboratories, personal fees from Teva, personal fees from Synexus, personal fees from Boehringer Ingelheim and personal fees from Zentiva, outside of the submitted work. Dr. Krishan reports non-financial support from the UGC Centre of Advanced Study, CAS II, Department of Anthropology, Panjab University, outside of the submitted work. Dr. Mendoza reports employment as a program analyst in Population and Development at the United Nations Population Fund-UNFPA Country Office in Peru, which does not necessarily endorse this study. Dr. Pandi-Perumal reports non-financial support from Somnogen Canada and personal fees from royalties, outside of the submitted work. Dr. Postma reports grants and personal fees from MSD, grants and personal fees from GSK, grants and personal fees from Pfizer, grants and personal fees from Boehringer Ingelheim, grants and personal fees from Novavax, personal fees from Quintiles, grants from Bayer, grants and personal fees from BMS, grants and personal fees from Astra Zeneca, grants and personal fees from Sanofi, personal fees from Novartis, personal fees from Pharmerit, other from Health-Ecore, other from PAG, other from Asc Academics, grants and personal fees from IQVIA, grants from bioMérieux, grants from the WHO, grants from the European Union, grants and personal fees from Seqirus, grants from FIND, grants from Antilope and grants from DIKTI, LPDP, Budi, all outside of the submitted work. Dr. Rezaehosseini reports grants from the Research Foundation of Rigshospitalet and grants from the A.P. Møller Fonden, outside of the submitted work. Dr. Shivarov reports salary from PRAHS, outside of the submitted work. Dr. Uddin reports as having worked as a visiting fellow at Deakin University Institute for Physical Activity and Nutrition (IPAN). IPAN paid for travel (including flights and transportation), accommodations and meals. E.Upadhyay is listed on two patents: 'A system and method of reusable filters for anti-pollution mask' (pending) and 'A system and method for electricity generation through crop stubble by using microbial fuel cells' (pending). Dr. Wu reports grants from the Ministry of Science and Technology in China, personal fees from HealthKeepers, grants from Suzhou Municipal Science and Technology Bureau and grants from Kunshan Government, outside of the submitted work. Dr. Zhu reports grants from UTHHealth Innovation for Cancer Prevention Research Training Program Pre-doctoral Fellowship (Cancer Prevention and Research Institute of Texas, grant no. RP160015), during the conduct of the study.

### Additional information

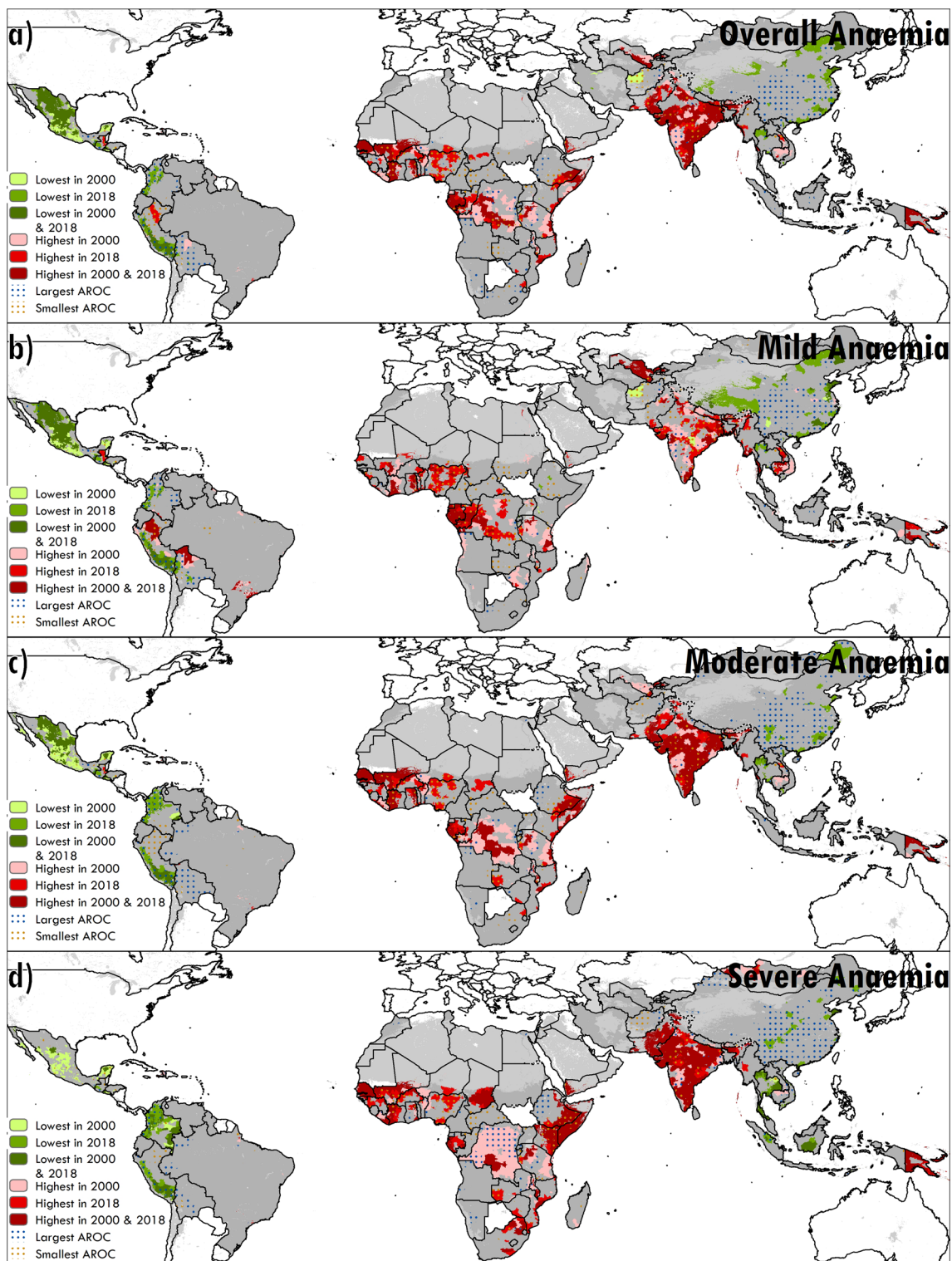
**Extended data** is available for this paper at <https://doi.org/10.1038/s41591-021-01498-0>.

**Supplementary information** The online version contains supplementary material available at <https://doi.org/10.1038/s41591-021-01498-0>.

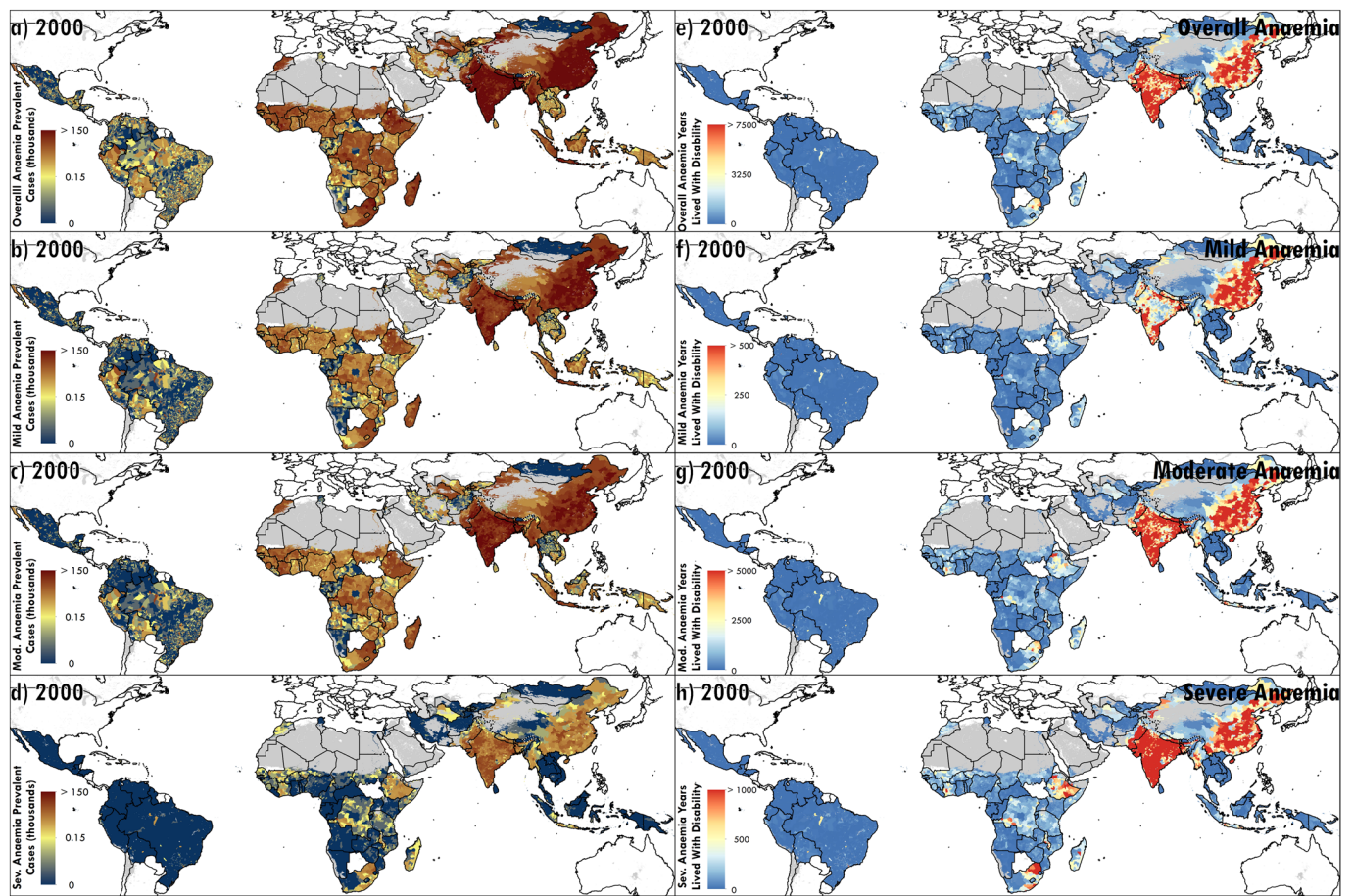
**Correspondence and requests for materials** should be addressed to Simon I. Hay.

**Reprints and permissions information** is available at [www.nature.com/reprints](http://www.nature.com/reprints).

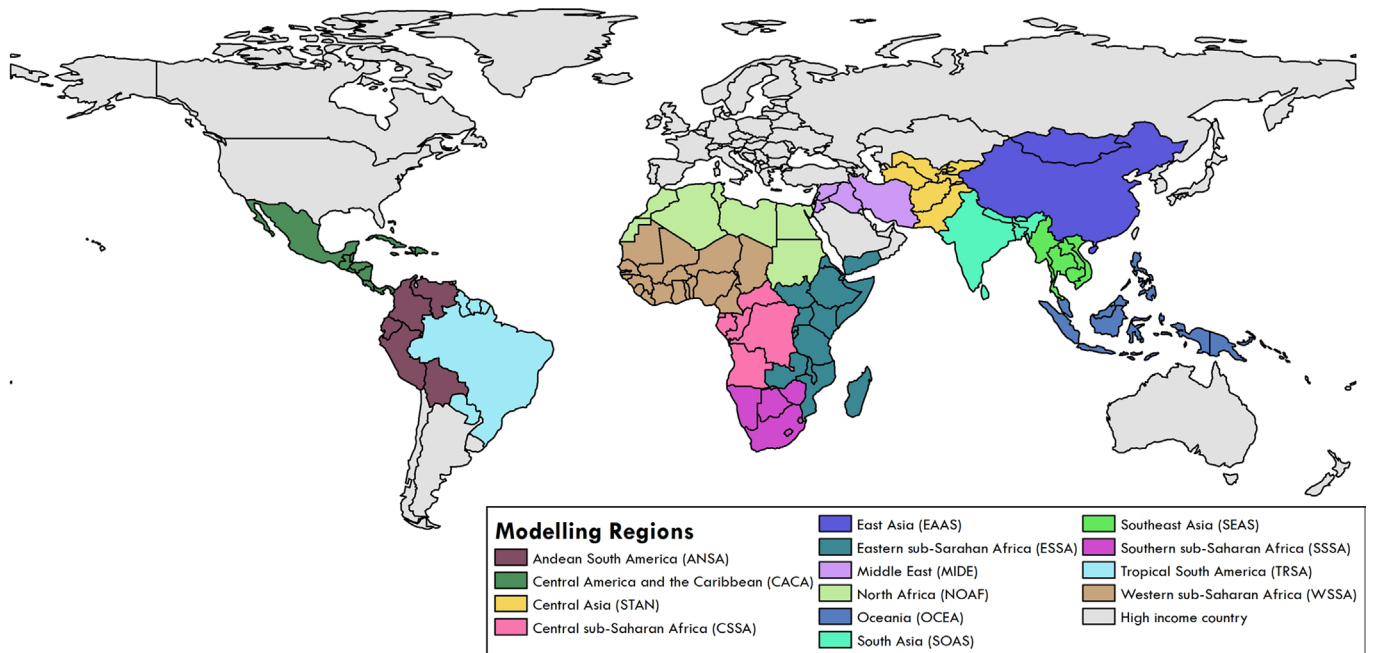
**Editor recognition statement** Jennifer Sargent was the primary editor on this article and managed its editorial process and peer review in collaboration with the rest of the editorial team. **Reviewer recognition statement** *Nature Medicine* thanks Ian Hambleton and the other, anonymous, reviewer(s) for their contribution to the peer review of this work.



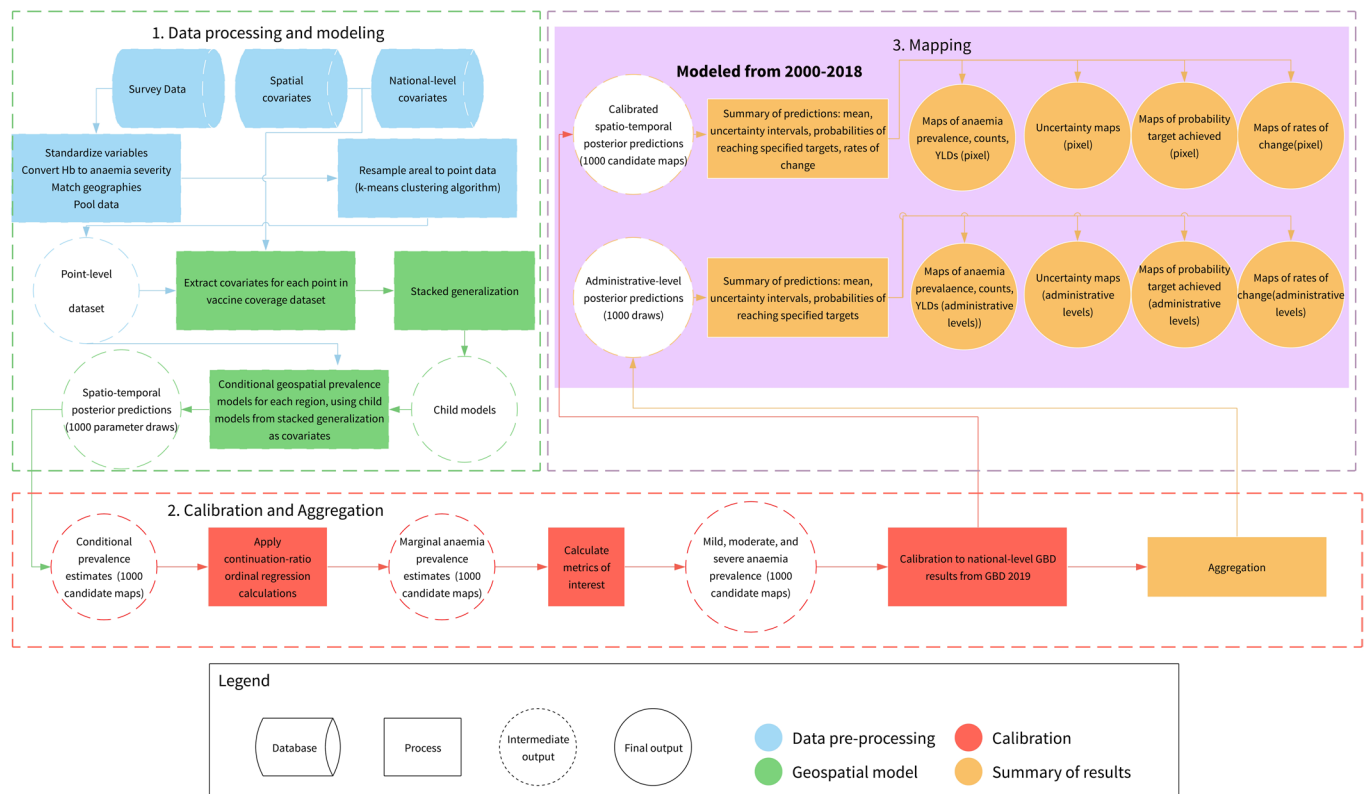
**Extended Data Fig. 1 | Highest- and lowest-performing second administrative-level units stratified by anaemia severity in women of reproductive age across LMICs (2000–2018).** **a–d**, Overlapping population-weighted highest and lowest deciles of prevalence and weighted annualised rates of change (AROC) by severity at the second administrative level between 2000 and 2018 for overall (**a**), mild (**b**), moderate (**c**), and severe anaemia (**d**) among WRA. Maps reflect administrative boundaries, land cover, lakes, and population; grey-coloured grid cells had fewer than ten people per 1 × 1-km grid cell and were classified as “barren or sparsely vegetated”, while white-coloured grid cells were not included in this analysis<sup>42–47</sup>.



**Extended Data Fig. 2 | Counts and years lived with disability (YLDs) by anaemia severity among WRA in 2000.** **a-d**, Number of WRA across 82 LMICs with overall (**a**), mild (**b**), moderate (**c**), and severe anaemia (**d**) in 2000 by second administrative-level units. **e-h**, Number of years lived with disability (YLDs) among women of reproductive age (WRA) attributable to overall (**e**), mild (**f**), moderate (**g**), and severe anaemia (**h**) in 2000 by second administrative-level units. Maps reflect administrative boundaries, land cover, lakes, and population; grey-coloured grid cells had fewer than ten people per 1 × 1-km grid cell and were classified as "barren or sparsely vegetated", while white-coloured grid cells were not included in this analysis<sup>42-47</sup>.



**Extended Data Fig. 3 | Modelling regions.** Modelling regions<sup>48</sup> were based on geographic and Socio-demographic Index (SDI) regions from the Global Burden of Disease<sup>18</sup>, defined as Andean South America, Central America and the Caribbean, Central sub-Saharan Africa (SSA), East Asia, Eastern SSA, Middle East, North Africa, Oceania, Southeast Asia, South Asia, South SSA, Central Asia, Tropical South America, and Western SSA. Regions in grey (Stage 3) were not included in our models due to high-middle and high SDI. Only 82 low- and middle-income countries (LMICs) were included in this study.



**Extended Data Fig. 4 | Modeling process flow diagram.** The geospatial modelling process consists of three main sections. First, all available survey data that can be referenced to a coordinate/point (for example, survey cluster) or small polygon (administrative) unit are compiled, Hb measurements are converted to anaemia severity, data matched to polygons are resampled into pseudo-points, covariates are merged onto the point-level dataset, a series of conditional geospatial model is fit using stacked generalization child models as main effects is fit for each geographic region, and 1000 posterior predictions are sampled from the fitted model. Second, the 1000 parameter draws are projected into 1000 5x5km pixel conditional prevalence candidate maps, converted into marginal anaemia severity prevalence maps, calibrated to GBD 2019 estimates, and aggregated to administrative levels. Lastly, the 1000 calibrated pixel and aggregated draws are summarized into estimates of anaemia prevalence, counts, YLDs, and the associated uncertainty, probabilities of meeting targets, and rates of change. See the Methods for more details.



## Reporting Summary

Nature Research wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Research policies, see our [Editorial Policies](#) and the [Editorial Policy Checklist](#).

### 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  
*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  
*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

Data analysis

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Research [guidelines for submitting code & software](#) for further information.

### 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 list of figures that have associated raw data
- A description of any restrictions on data availability

The findings of this study are supported by data that are available in public online repositories, data that are publicly available on request from the data provider, and data that are not publicly available due to restrictions by the data provider and which were used under license for the current study. Details on data sources can be found on the GHDx website including information about the data provider and links to where the data can be accessed or requested (where available). We have also provided maps of the data included in our models in Supplementary Figures 1–5. Outputs of these analyses can be explored at various spatial levels (national, administrative, and 5 × 5-km levels) through our customized visualisation tool (<http://ghdx.healthdata.org/record/ihme-data/global-anemia-prevalence-geospatial-estimates-2000-2019>) and at <https://github.com/ihmeuw/lbd/tree/anemia-lmic-2021>.

Administrative boundaries were retrieved from the Global Administrative Unit Layers (GAUL) dataset, implemented by the FAO within the CountrySTAT and

Agricultural Market Information System (AMIS) projects. Land cover was retrieved from the online Data Pool, courtesy of the NASA EOSDIS Land Processes Distributed Active Archive Center, USGS/Earth Resources Observation and Science Center, Sioux Falls, South Dakota. Lakes were retrieved from the Global Lakes and Wetlands Database, courtesy of the World Wildlife Fund and the Center for Environmental Systems Research, University of Kassel. Populations were retrieved from WorldPop.

## Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

Life sciences       Behavioural & social sciences       Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see [nature.com/documents/nr-reporting-summary-flat.pdf](https://nature.com/documents/nr-reporting-summary-flat.pdf)

## Life sciences study design

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

Sample size	Sample size was calculated as the number of unique data source-location pairs with survey responses in order to estimate prevalence of Anemia among women of reproductive age group (15-49 years). This sample size is reported in the methods section: "Included across our models were 218 geo-referenced household surveys from 2000 to 2018 representing over 3 million WRA. Each individual woman's record was associated with a cluster, a group of neighbouring households, or a "community" that acted as a primary sampling unit in the survey design. The 218 surveys with haemoglobin, pregnancy, smoking, and elevation data included geographic coordinates or precise place names for each cluster within that survey." This is an observational study with no hypothesis testing and the sample size was not pre-specified. We evaluate the overall performance of our modelling strategy, given the available data, as part of a validation exercise as described in the 'Model validation' section of the methods, and as reported in the Supplementary Information (Supplementary Section 6.0).
Data exclusions	Select data sources were excluded for the following reasons: missing survey weights for areal data, missing sex or age variable, incomplete sampling (e.g., only women aged 20–24 years measured), or untrustworthy data (as determined by the survey administrator or by inspection). Data availability plots for anaemia by country, data type, and year can be found in Supplementary Figures 1–5. A list of low- and middle-income countries excluded from the model due to lack of available data can be found in Supplementary Table 3.
Replication	This is an observational study using many years of survey and report data and in principle could be replicated. Due to the time required to extract, process, and geo-locate all data, as well as to run the statistical models, we have not undertaken an explicit replication analysis.
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 report 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	Involvement in the study
<input checked="" type="checkbox"/>	<input type="checkbox"/> Antibodies
<input checked="" type="checkbox"/>	<input type="checkbox"/> Eukaryotic cell lines
<input checked="" type="checkbox"/>	<input type="checkbox"/> Palaeontology and archaeology
<input checked="" type="checkbox"/>	<input type="checkbox"/> Animals and other organisms
<input checked="" type="checkbox"/>	<input type="checkbox"/> Human research participants
<input checked="" type="checkbox"/>	<input type="checkbox"/> Clinical data
<input checked="" type="checkbox"/>	<input type="checkbox"/> Dual use research of concern

### Methods

n/a	Involvement in the study
<input checked="" type="checkbox"/>	<input type="checkbox"/> ChIP-seq
<input checked="" type="checkbox"/>	<input type="checkbox"/> Flow cytometry
<input checked="" type="checkbox"/>	<input type="checkbox"/> MRI-based neuroimaging