Underestimating the risks of overpopulation endangers the health and lives of future children

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Abstract
The risks of climate change to children have been widely discussed, but the risks of overpopulation have not been similarly scrutinised. Projections of the health and mortality rates of infants and children have largely ignored overpopulation; for example, the United Nation's projections of infant mortality to 2100 disregard the influences of rapidly increasing populations in low- and middle-income countries and a deteriorating climate. In this paper, we first summarise the evidence that a large and growing human population will increase child mortality, and compromise health and wellbeing this century. Population growth increases the pace and magnitude of climate change because the degree of climate disruption is a product of per-capita consumption and total population size. Population growth also increases overcrowding, which in turn increases local and global air pollution, disease transmission, and resource scarcity, all of which have disproportionate effects on children compared to adults. To gain insight into the potential risks that children will face this century, we analysed the United Nation's *Medium* and *High* population projections for this century to show that between 9.91 billion and 14.49 billion children will be born from 2022 to 2100, and that most (> 60%) will be born in sub-Saharan Africa and Central/South Asia (6.19 billion and 9.10 billion, 62.5% and 61.4% of all births, *Medium* and *High* projections, respectively), where malnutrition is already high and capacity lowest to increase crop yields accordingly. We then identify areas where future child mortality can be expected to be higher than current predictions. We show that the lowest-income nations with the highest population growth have the fewest resources to protect increasing numbers of children from the deteriorating climate and the risks of overcrowding. We emphasise the urgent need for appropriate, quality, free, non-coercive, family-planning services to be universally available to allow men and women the opportunity to choose the size of their family. In summary, we provide the first evaluation of the evidence that overpopulation is already adversely affecting children and the evidence that there will be increasingly serious consequences for children if population growth continues at its current pace.

Key words: air pollution, child health, climate change, consumption, environment, overshoot, paediatrics, sustainability

Introduction
The health and wellbeing of children should be one of society's highest priorities, not just for children today,

but also for children of the future. The demonstrated and potential effects of climate change on children's health have received considerable discussion (1-3) and many regional analyses, although only one analysis of its potential global magnitude (4). In contrast, the impact of human overpopulation on current children and the fate of future children is rarely discussed (5-7), and is mostly overlooked as a major factor affecting child health. This is evidenced by the current United Nations' projections of infant mortality to 2100 (8) that ignore the effects of a deteriorating climate and increasing population that will disproportionately affect children in the lowest-income nations (8, 9).

The required changes to protect the Earth's environment are now well-understood and include rapidly decarbonising the atmosphere (10, 11), preserving biodiversity (12-14), and protecting the natural environment (12, 15). The changes needed to protect children by slowing and then reversing human population growth have received less attention, even though an important component is the provision of universal, freely available, voluntary, socially and culturally appropriate, and quality family-planning services (5, 16, 17), as enshrined in the United Nation's Sustainable Development Goal 5. A better appreciation of the threats facing future children is important to catalyse governments, policy makers, non-government organisations, and human society in general to commit to the changes needed to address both climate change and overpopulation.

The aim of our paper is therefore to provide the first summary of the existing evidence that overpopulation has already affected children's health. We then use published projections of population growth to provide evidence that a large and growing human population threatens the health and wellbeing of an increasing number of children as this century progresses.

Quantifying the global increase in population

Since civilisation began, human societies have developed new technologies allowing rapid environmental exploitation and a commensurate population expansion. The size of the global human population was around 7 million 12,000 years ago (18, 19) (Fig. 1), and for the next 8,000 years, grew at an average per-capita rate of 0.0237% year^{-1} to reach 232 million by year 0 AD (20) (Fig. 1). This rate progressively increased from year 0 to the current rate of 0.9% per year (19), which is more than 36 times higher and modifies a population that is over 1000 times larger than it was 12,000 years ago. Regardless, many global authorities have asserted that the world's population growth rate is slowing (19, 21), but this deceptively reassuring conclusion ignores that the decreasing component is the *per capita* rate — that since 1981, the number of new people added to the population has remained > 80 million *each year* until COVID intervened in 2020 (22) (Fig. 1). To put this in perspective, for the last four decades, the world population has increased by more than the world's entire population 12,000 years ago *every five weeks*. This 'overshoot' has strained on our planet's capacity to provide for the current human population (23), with children especially vulnerable to the environmental consequences (24, 25)

Figure 1: (a) Trajectory of the global population over the last 12,000 years (source: ourworldindata.org). (b) Inset shows the trajectory from 1900–2022. (c) Number of new persons added each year to the world population since 10,000 BCE. (d) Number of new persons added each year from 1900–2022.
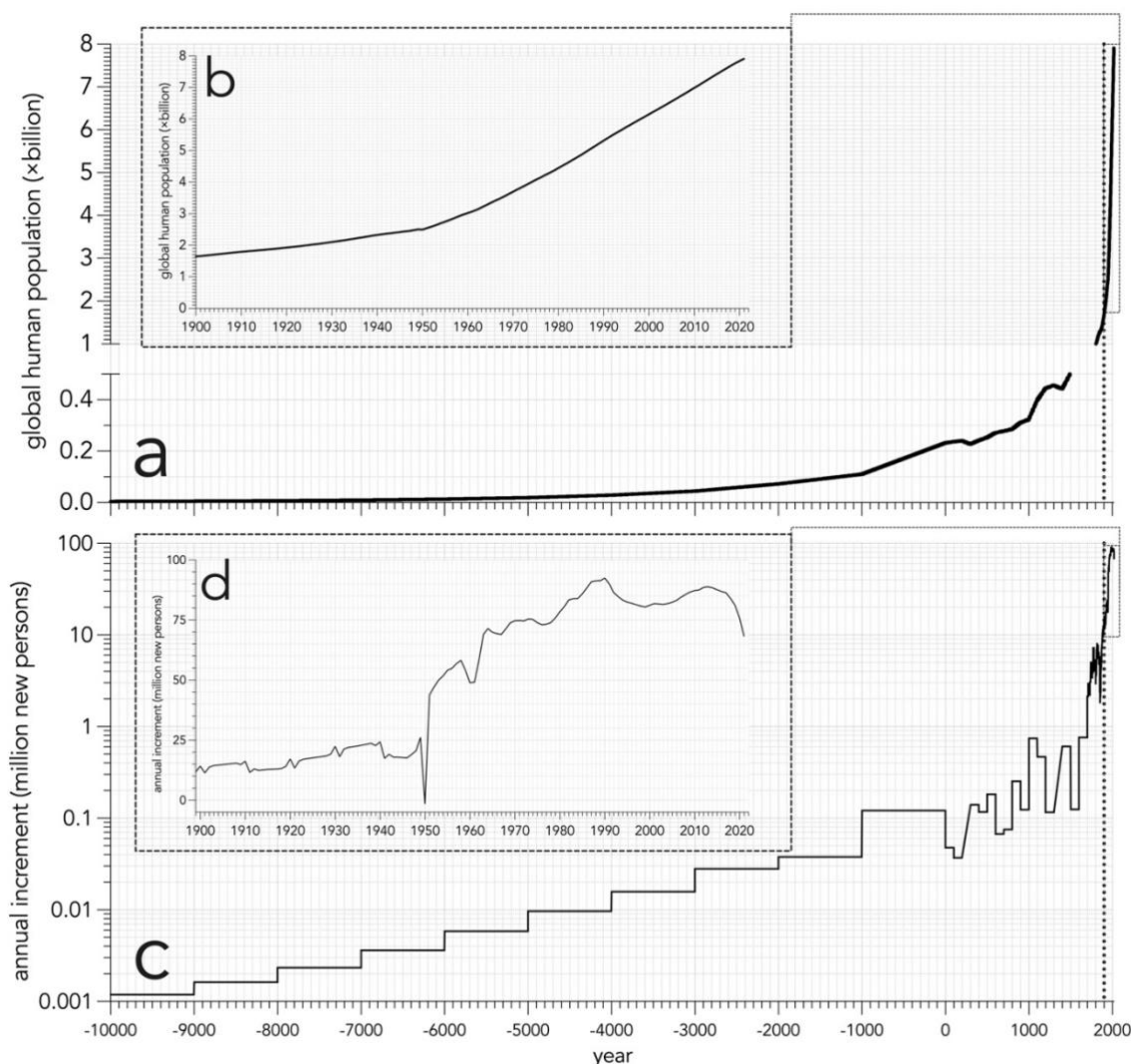
Population growth has strained the planet's biocapacity

In 1992, Rees (26) described the concept of the 'ecological footprint', and calculated that humans were taking around 60% more from their environment than the environment could sustain. With an increasing population, this percentage has risen to 71% (27) and this 'ecological overshoot' causes major damage to every aspect of the natural environment (15, 28). The changes might already be irreversible (29-31), but there is agreement that even if strong action is taken immediately, the global climate will inevitably become more hostile over the coming years (30, 31). In short, our planet's ability to sustain a healthy existence for an increasing number of children and adults was passed long ago, yet our population continues to increase (5, 29).

'Overpopulation' can be defined several ways, but in general occurs when the number of individuals of a given species exceeds the number its environment can sustain (32). There is still no universal agreement that the planet is overpopulated, with dissenters from the United Nations (33), science communication (34-36), and even scientists (37). Such 'overpopulation denialists' (38) emphasise the ability of the planet to continue to feed its populace (35, 37) and ignore the short-term nature of their arguments (35), as well as the continuing destruction of the biosphere and accelerating extinction of species (39). In contrast, Rees's (26) carefully

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considered thesis and focus on rising per-capita resource consumption, especially in wealthy countries (13), along with mounting environmental destruction (15), identify that overpopulation is a real problem and challenge (7, 15, 40). Reasons why overpopulation has received little attention (5-7) could be that society tends to ignore "… data that do not fit with its myths and metaphors" (41, 42).

Addressing inequity and global justice are paramount for securing the future of children, as is recognising that high-income nations are responsible for most global consumption while being simultaneously the least vulnerable to its consequences (43). The effect of global overpopulation on environmental integrity is largely due to the activities of high-income countries, so it follows that reductions in both consumption and population size are important components of reducing environmental damage (5, 44). For low- and middle-income nations, adhering to the United Nation's Sustainable Development Goal 5 would help insulate future generations of children from the consequences of environmental decay and limited health resources in response (45). Reducing infant mortality is also an important aspect of reducing fertility rates in low- and middle-income countries (46). Equitable sharing of sustainable natural resources among all nations (47) would also reduce poverty and hence, infant mortality and fertility in poorer countries (46). The economic circumstances of nations vary greatly, but the need to reduce population growth and reverse trends applies to all societies (5). Warnings that an aging society resulting from reducing global population will have serious adverse consequences on humanity have been proposed without supporting evidence to the contrary (28).

Why humans have done so much to improve their own situation in the short term, but so little to stop damaging the planet in the long term, is a valid question. The contribution of an increasing global population to environmental damage is now well-established (15, 23, 28)(48). Population size is an inherent component of climate change, because environmental impact is the product of per capita consumption and population size. Consumption is also driven by economic factors described in the full report of the Sixth Assessment of Intergovernmental Panel on Climate Change (IPCC) (44), which stated unequivocally that: "Globally, gross domestic product (GDP) per capita and population growth remained the strongest drivers of CO_2 emissions from fossil fuel combustion in the last decade". Why population size was not mentioned in the IPPC's summary report (30) or in that of the 27th Conference of the Parties in 2022 (11) is unclear, but could reflect the global reluctance to address overpopulation (6, 41). The relationship between population size and climate change is by no means simple given the inequities in individual and national resource consumption, access to resources, and economic capacity (49, 50). If the global human population had stabilised at one or two billion (below the estimated maximal sustainable global footprint) (51), climate disruption would not have occurred, or at least it would have been of lower magnitude and progressed at a slower rate (31).

Although the climate-change component of environmental damage has received widespread attention and calls for action, greenhouse-gas emissions (both total and per-capita) have continued to rise almost linearly (52), which not even the COVID-19 pandemic could slow (52-54). The rapid rise in renewable energy has also not slowed this increase, a poignant demonstration of Jevon's paradox (55) — increasing efficiency in resource use tends to increase the total use of that resource. Regardless of how we generate energy, more energy consumption is likely to increase environmental damage (31), making the planet less hospitable for children. In short, the evidence that too many humans are taking too much from the planet is irrefutable, yet our total population and consumption continue to increase much as they have over the last 50 years, and efforts to change these trajectories have had little discernible effect.

Overpopulation is already adversely affecting children's health
Major scientific and humanitarian advances have reduced infant and child mortality over recent decades (13, 56), although high mortality still occurs in low- and middle-income countries (8). Escalating environmental damage and climate change, combined with an increasing population, now threaten to reverse these

improvements (1, 44). Whereas high-income countries have the resources to insulate children from some of the immediate threats, this might not be the case with further environmental deterioration. In the following sections, we summarise why low- and middle-income nations with fewer resources and higher populations are already less able to provide a healthy environment for children, and will be less able to do so in the future (57-59).

The consequences of overpopulation are already worsening children's health and wellbeing. Within the family unit, too many children for the family's space or resources strain a family's economic capacity to care for the health of their children. Indeed, overcrowding measured by household size is associated with a higher rate of childhood mortality in African nations (60). At an urban scale, rapid urbanisation and overcrowding are also associated with increases in the risk of developing infectious diseases (61), and communicable (62) and non-communicable diseases (63, 64).
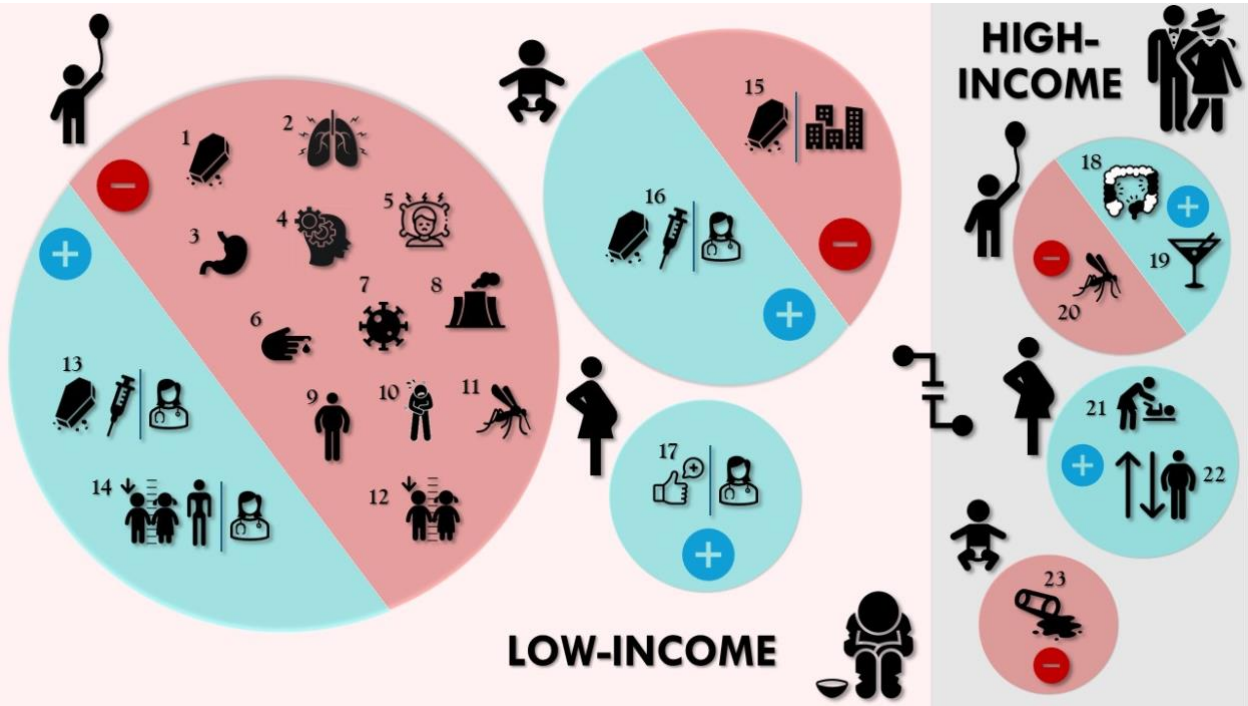
City size correlates with population density (65, 66), and although relationships are complex and affected by local factors (66), population density correlates with air pollution in both low- (67) and high-income (66) countries. City size has a strong influence on air quality in low- and middle-income countries (66, 67). The five African cities with the highest populations also have the highest concentrations of (particulate matter) $PM_{2.5}$ (67). Mega-cities in India are among the most polluted cities in the world (68). The correlation between city size, population density, and air pollution is concerning, because air pollution is a major cause of childhood respiratory disease (69) and mortality (57). For each 10 µg m^{-3} increase in $PM_{2.5}$, there is a 9% (95% confidence interval: 4–14%) rise in infant mortality in African countries (57). Nigeria, Democratic Republic of the Congo, and Ethiopia with high population growth had more people exposed to poor air quality in 2019 despite reductions in the use of solid fuels for cooking (67). Overall, air pollution in Africa caused an estimated 449,000 additional infant deaths in 2015 (57).

The spread of non-communicable and infectious diseases is facilitated by household overcrowding that increases with urbanisation (70). Although initially benefitting children by increasing the availability of health services (71) and reducing the prevalence of undernutrition (64), rapid urbanisation (a surrogate for high population density) increases the incidence of chronic diseases by adulthood (64), aids the rapid transmission of infectious disease (71), and is associated with increases in many infectious diseases, including pneumonia (61), diarrhoea (72), malaria (73), tuberculosis (74), yellow fever (75), Ebola (76), HIV (77), cholera (78), and many zoonotic diseases including COVID-19 (79). Hence, overpopulation not only inhibits growth in children, but also increases the conditions arising from breathing polluted air, most infectious diseases, and potentially more pandemics.

To evaluate how population density affects child health in greater detail, we examined the published evidence for this relationship. A literature search using the terms "population density" OR "overpopulation" & "child health", between 2015 and 2024, identified 40 papers showing an effect of population density on child-health outcomes. A summary of results is shown in Fig. 2 and the full review is available in Supplementary Appendix 1. There is evidence for many aspects of child health being eroded by increasing population density, but there was a clear distinction between lower- and higher-income countries. High population density in lower-income countries is linked to both negative and positive child health outcomes; however, every positive child health outcome was facilitated by increased access to healthcare rather than a direct benefit from population density itself. Those directly related to population show increasing density worsened child health in lower-income countries. Because most future children will be born in developing countries, there is a disproportionate negative effect of higher population densities on most children worldwide. Population density also had mixed effects on child health in higher-income countries; however, it appears that these children are buffered from many of the worst health outcomes.

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207 **Figure 2.** Effects of population density on child, infant, and maternal health.

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210
211 **legend**

Low-income nations (left panel)	
Negative effects (red) on children	**1**. ↑ mortality; **2**. ↑ respiratory disease; **3**. ↑ gastrointestinal/enteric disease; **4**. ↓ cognitive ability; **5**. ↑ sleep disorders; **6**. ↑ diabetes; **7**. ↑ COVID; **8**. ↑ air pollution & resultant disease; **9**. ↑ body mass index; **10**. ↑ typhoid; **11**. ↑ vector-borne disease (e.g., dengue): **12**. ↑ stunting
Positive effects (blue) on children	**13**. ↓ mortality & ↑ vaccination rate due to ↑ health care; **14**. ↓ stunting/wasting/underweight due to ↑ health care
Negative effects on infants	**15**. ↑ mortality due to ↑ urbanisation
Positive effects (red) on infants	**16**. ↓ mortality & ↑ vaccination rate due to ↑ health care
Positive effects (blue) on pregnant women	**17**. better maternal outcomes due to ↑ health care
High-income nations (right panel)	
Positive effects (blue) on children	**18**. ↓ irritable bowel syndrome; **19**. ↓ binge drinking
Negative effects (red) on children	**20**. ↑ zoonotic disease transmission
Positive (or equivocal) effects on pregnant women	**21**. ↓ teenage pregnancy; **22**. ↑ or ↓ body mass index
Negative effects (red) on infants	**23**. ↑ fungal contamination of human milk

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Larger populations will adversely affect all future children

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214 Despite high-income countries having more capacity to buffer children from future shocks, overcrowding can
215 reduce access to green space and erode mental health and wellbeing (80-82), increase pre-term births (83),
216 harm lung function (80), and lead to more respiratory diseases (84). Australia is an example of a high-income
217 nation with high net immigration; overall, its population growth exceeded 1.5% year^{-1} prior to the COVID-19
218 pandemic (85), and increased to 2.4% thereafter (86). Australia, like many resource-rich countries, relies on
219 immigration to maintain and expand its economy, and its population will more than triple by the end of the

century if the current growth rate continues (85, 87). Feeding > 70 million people will be difficult given that Australia currently produces food for around 60 million people (88), a precarious situation given the country's relatively infertile and fragile soils (89, 90) and the compounding negative effects of climate change on crop yields (91-93)(94). Australia might therefore be unable to feed its own population by 2100 (88). This would have serious consequences, because it currently exports 72% of its food production (95) and would cease its role as a major global food supplier by 2050 (92, 94).

With projected increases in the global population, food supply will need to increase by between 50 and 70% by 2050 to maintain the current nourishment supply worldwide (93), even though this supply (or at least, its equitable distribution) is already inadequate (96, 97). This increase will require 70 million hectares of additional land for planting crops (96), which will be lower-quality and require more resources to maintain yields (including irrigation), thereby eroding biodiversity further (39). Whether such an increased rate of production is possible in the face of climate change is uncertain because yields will also decline with warming (98-102). Because 80–90% of irrigation potential is already realised, expansion is limited in the face of potential reductions in precipitation (96). Technology has slowed the time to reach the point where food demand outstrips available arable land, leading some to downplay (35) or disregard whether this will occur (35, 36). The 'green revolution's' improvements in agricultural technology aimed to reduce undernourishment by striking a balance between growth in population and food production (103), but the recent increase in undernourishment and the lack of additional arable land suggest that this aim can no longer be met (104). This situation is not helped by meat consumption continuing to increase (105), despite the higher environmental costs of its production (105). Based on current evidence, avoiding further increases in malnutrition and stunting in young children, with its associated increases in child mortality from other diseases (106, 107), will be difficult to avoid.

Children in low- and middle-income nations will be most affected by future increases in population because they live in the places where population growth is highest (108), the environment is most fragile, agricultural production is the lowest (109), and economic resources to address these issues are most limited. Indeed, a study examining child-health data from every African country demonstrated that environmental degradation (110) driven by high population growth rates impairs child health (60). However, the predicted scale and nature of future impacts will depend on many interacting factors, including the success of interventions to reduce environmental damage, economic development, national and international environmental policies, and public-health initiatives.

If the availability of the resources required to maximise health does not increase proportionally to population growth, the average health of children will decline. The number of undernourished people worldwide had been gradually reducing to an estimated 573.3 million in 2017, but then increased to 767.9 million in 2021, a 33.9% increase in 4 years (104); the latest estimates that include effects of the COVID-19 pandemic place the number as high as 828 million (104). The Food and Agriculture Organization's recent report also estimates that that the COVID-19 pandemic added 79 million people to the previous estimates of those undernourished (104). The United Nations International Children's Emergency Fund estimated in 2022 that stunting was present in 22.3% of children under 5 years of age globally, and in 33.5%, 28.1%, 8.3%, and 4.0% in low-, lower-middle, upper-middle, and high-income countries, respectively, and 31.5% of children in sub-Saharan Africa (111). Their reports have expressed concern regarding Sustainable Development Goal 2.2 relating to eradicating stunting (13, 99).

The World Health Organization has estimated that malnutrition is responsible for 45% of all childhood deaths in low- and middle-income countries (112, 113), because malnutrition increases mortality from infectious diseases, especially acute respiratory infections (106, 107). Malnutrition in parts of sub-Saharan Africa is also

268 a driver of low educational status and economic damage (102), and both these outcomes will feed back to
269 erode children's health (102).
270
271 **Relationships between overpopulation, climate change, and child health**
272 The number of children adversely affected by climate change will increase not only because there will be
273 more children, but because of the increasing number of vulnerable children (114-116). The latest
274 Intergovernmental Panel on Climate Change report states with "very high confidence" that climate change has
275 already harmed children's health, including most aspects of their physical and mental health (2, 117). Indeed,
276 a deteriorating environment will have adverse effects of on most organ systems (118) — rising ambient
277 temperature and more frequent and intense heat waves, as well as worsening air pollution increase medical
278 problems in children (119). The effects of climate change on children's health has been summarised recently in the
279 first meta-analysis of all available published evidence (4). The greatest effects were in increases in preterm births
280 and respiratory disease (4). Individual studies have also shown increases in preterm births (120-122), as well as
281 respiratory infections (123, 124), asthma (114, 115, 125, 126), kidney damage (127, 128), diabetes (129-132),
282 diarrhoeal diseases (125, 133, 134), malaria (135), presentations to emergency departments (126, 136-138), heat
283 stroke, organ failure (139, 140), and mental health problems (119, 141). Even more concerning, the
284 concentration of atmospheric CO_2 expected by 2100 could directly damage mammalian brain and respiratory
285 development prior to birth (142, 143).
286
287 Adverse perinatal outcomes worsen with climate change. The risk of preterm birth is already higher in low-
288 and middle-income countries (120, 144) and is projected to increase (144). Globally, the risk increases with
289 ambient temperature and heatwaves (4, 83, 122, 144, 145), and with lower socio-economic status (120). Preterm
290 birth is a major contributor to infant mortality and lifelong health problems, including neurological impairment, chronic
291 respiratory impairment, reduced growth, and other disorders (144, 146). Little is known about the pathophysiological
292 mechanisms by which high temperatures increase preterm births, but a thermoregulatory problem in pregnant
293 women exposed to extreme heat resulting in aberrant inflammatory responses has been proposed (147), and
294 cortisol-induced uterine activity due to prostaglandin release has also been postulated (120, 147). More
295 research to improve understanding of these mechanisms to develop strategies to mitigate the risk is required
296 (147). In the meantime, resources are already scarce for maintaining children's health in low- and middle-income
297 nations (1, 144), so a rapidly increasing population combined with climate change will *ipso facto* exacerbate preterm
298 birth rates and further increase infant and child mortality (144).
299
300 Children's respiratory health is particularly vulnerable to overpopulation and climate change (66, 67, 69, 106,
301 107). Globally, high temperatures increase the risk of respiratory disease in children (4). In Indonesia, Brazil,
302 and India, high humidity increases the prevalence of childhood pneumonia (148). Pollutant exposure
303 associated with climate change correlates with an increase in the prevalence of asthma, atopic dermatitis, and
304 allergic rhinitis (149, 150). Air pollution is responsible for an estimated 236,000 deaths in the first month of
305 life of newborns in Africa, and with 14% of all deaths in children under the age of 5 across that continent (67).
306 Extreme temperature exposure and heat waves have also been associated with increased paediatric
307 presentations to hospital for asthma in Australia (152), USA (119, 152), and South Africa (116). Child health
308 will deteriorate as the climate changes, but this relationship is complex and influenced by many confounding
309 factors, such as existing local climate conditions, infrastructure, and socio-economic status (153, 154).
310
311 Climate change already strains systems that are essential for maintaining good child health, but particularly on
312 those unable to cope with current numbers of children (1). Climate change also reduces food security (94),
313 forces migration (155), and increases conflict (156). The latter leads to malnutrition, fewer educational
314 opportunities for children, and more barriers to receiving health care (156). For every 1 °C increase in
315 temperature, wheat production is expected to decline by 6% (157); hence, climate change and a rising

population will increase the number of children suffering from malnutrition. In Ethiopia, a 1 °C increase in average ambient temperature during pregnancy is associated with a 28% rise in the risk of developing stunting during early life (158). This could be explained, at least in part, by temperature-driven reduction in crop yields that weaken food security integral to sustaining maternal and neonatal nutrition. Low- and middle-income nations that already have poor food security will be at greater risk of facing the poor health outcomes associated with climate change.

To examine the susceptibility of future children to climate change, we examined the relationship between the numbers of children born in each country for the remainder of the century and the children's climate risk index (159, 160) (Fig. 3). There is a positive relationship between countries with the most children predicted to be born up to 2100 and a higher child climate risk index (Fig. 3). This shows that, in general, countries where the climate risk is highest are those with the greatest numbers of children born.

Figure 3. Number of children < 1 years old expected to be born and survive between 2022 and 2100 compared to the UNICEF child vulnerability score.
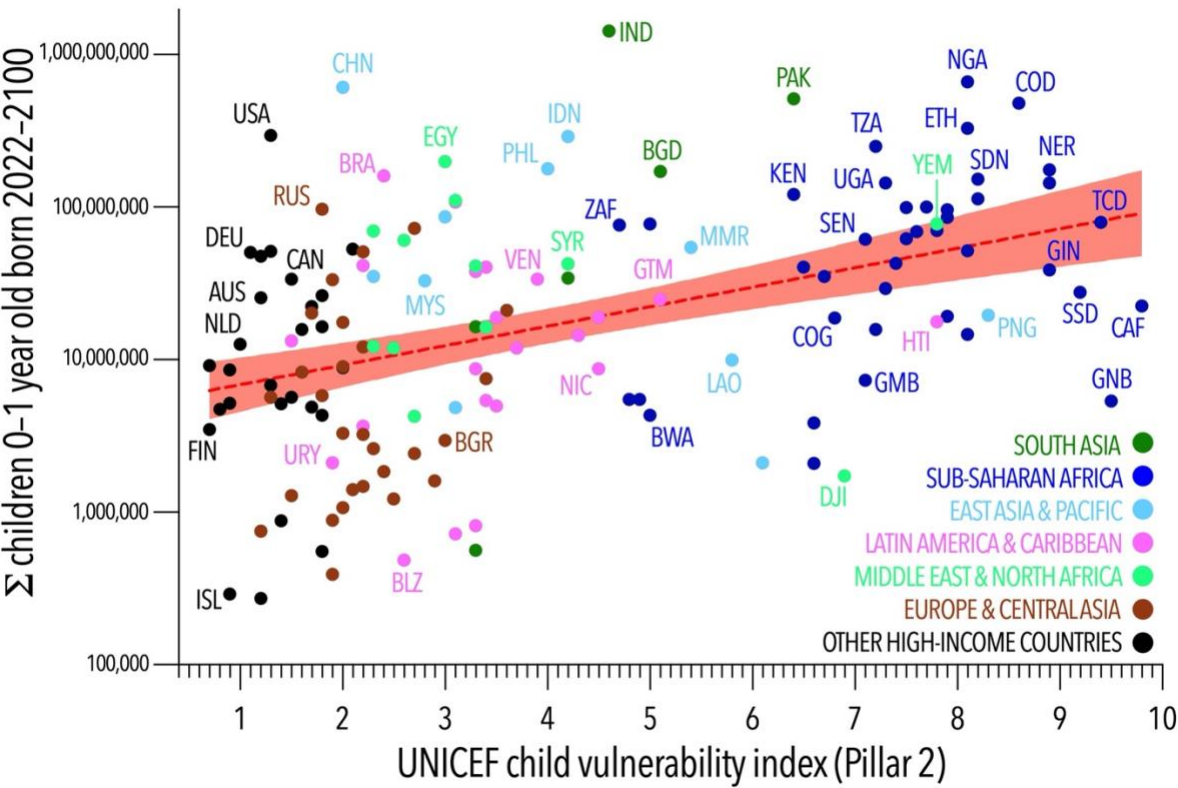

Country codes shown: AUS = Australia, BGD = Bangladesh, BGR = Bulgaria, BWA = Botswana, BRA = Brazil, BLZ = Belize, CAF = Central African Republic, CAN = Canada, CHN = China, COD = Democratic Republic of Congo, COG = Republic of Congo, DEU = Germany, DJI = Djibouti, EGY = Egypt, ETH = Ethiopia, FIN = Finland, GIN = Guinea, GMB = Gambia, GNB = Guinea-Bissau, GTM = Guatemala, HTI = Haiti, IDN = Indonesia, IND = India, ISL = Island, KEN = Kenya, LAO = Laos, MMR = Myanmar, MYS = Malaysia, NER = Niger, NGA = Nigeria, NIC = Nicaragua, NLD = Netherlands, PAK = Pakistan, PHL = Philippines, PNG = Papua New Guinea, RUS = Russia, SDN = Sudan, SEN = Senegal, SSD = South Sudan, SYR = Syria, TCD = Chad, TZA = Tanzania, UGA = Uganda, URY = Uruguay, USA = United States, VEN = Venezuela, YEM = Yemen, ZAF = South Africa.

Most children born this century will live in the poorest regions

To quantify the scale of the problem that increasing population growth will have on future children, we calculated the number of infants projected to be born this century and the regions and countries where they will be born. We used open source projections for this century produced by the United Nations (22) for all

projections. The United Nations' *Medium* and *High* population growth models (161) predict 9.91 billion and 14.49 billion children, respectively will be born globally between 2023 and 2100 (Fig. 4). For comparison, there were 134 million children born globally in 2021 (162), and there were 2.01 billion children aged 0–14 years in the world in 2022 (163).

Figure 4. Annual numbers of children < 1 years old expected to be born between 2022 and 2100 for each world region for the United Nations' *Medium* (a) and *High* (b) growth models.
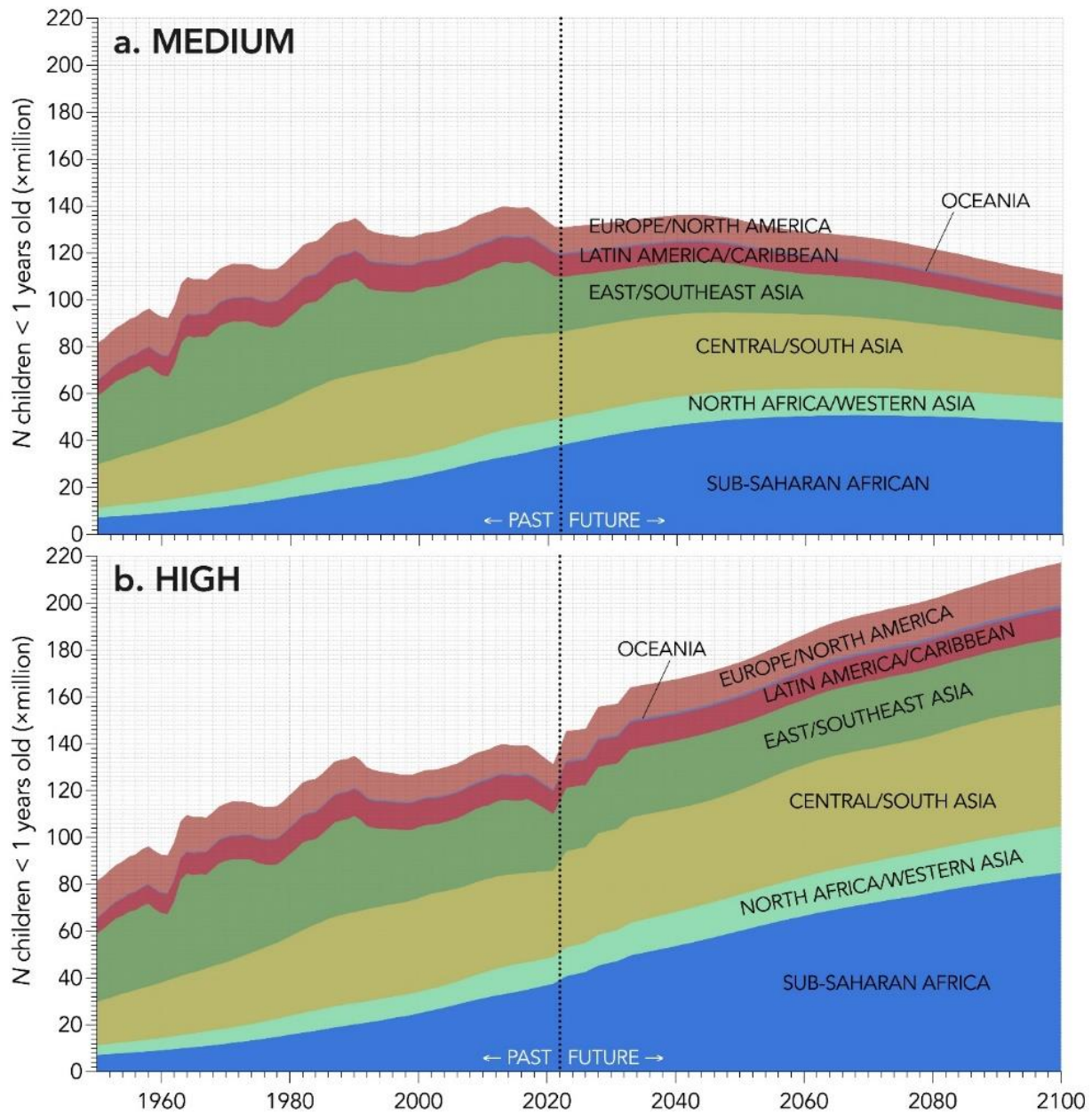
The region with the highest number of births is sub-Saharan Africa, where between 3.75 billion (*Medium*) and 5.13 billion (*High*) children are predicted to be born by 2100 (Fig. 4), followed by Central/South Asia (2.44 billion to 3.67 billion, respectively), East/Southeast Asia (1.41 billion to 2.22 billion), North Africa/Western Asia (0.89 to 1.29 billion), Europe/North America (0.78 to 1.19 billion), Latin America/Caribbean (0.58 to 0.90 billion), and Oceania (0.06 to 0.09 billion).

Sub-Saharan Africa is by far the poorest region in the world (162), where 22 (45.8%) of the 48 countries

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therein are classified as 'low-income' and 41 (85.4%) are classified as low- or lower-middle income. Sub-Saharan Africa also includes 22 of the world's 26 low-income countries (164). The region where the highest number of children will be born this century is also by far the poorest (see also Fig. 5). With the forecasted numbers of children in the poorest regions, there is no consideration in the United Nation's infant mortality projections for increasing mortality due to the consequences of not being able to feed these additional children (8). The problem for children in regions such as sub-Saharan Africa is not just in increased numbers to feed, it also includes the consequences of the projected decrease in crop yields as the climate deteriorates this century (98-102).

Figure 5. Projected annual ratio of children < 1 years old born to number of children < 1 years old born in 2022 for each world region based on the United Nations' *Medium* (a) and *High* (b) growth models. Horizontal black dotted line indicates a ratio = 1.
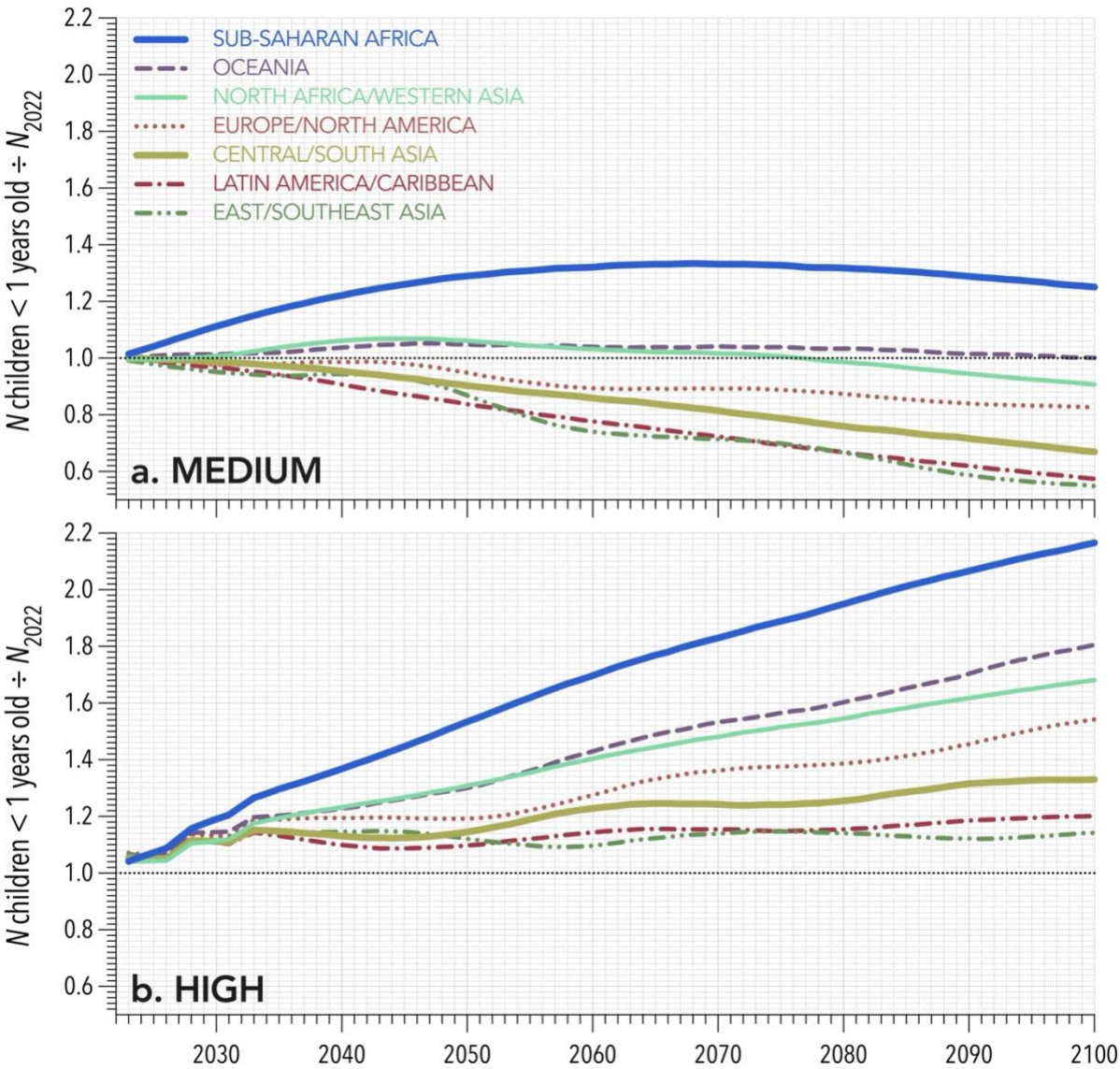

Interrelationships between population increase, poverty, and infant death

Poverty is a well-established predictor of infant and child mortality (165-168), so to determine which regions will have the highest burden of child mortality, we need to control for relative poverty among nations. Further,

larger populations will *ipso facto* produce more child mortalities over any time frame, so we also need to correct for population size when comparing regions or nations for the future burden of child mortality.

We obtained national poverty data from the World Bank (data.worldbank.org), measured as the poverty headcount ratio at national poverty lines (i.e., proportion of the population living below national poverty lines for the most recent available year for each country, expressed on the logit scale to linearise the data). We then summed the projected number of child (0–1 year old) mortalities from 2022 to 2100 from United Nations World Population Prospects 2022 (number of deaths by single age) under the *Medium* projection variant (population.un.org/wpp). We divided the sum of projected child (0–1 years old) deaths from 2022 to 2100 by the number of 0–1-year olds projected to be born in 2100 by country to control for relative population size (expressed on the square-root scale to linearise the data). Figure 6 shows the relationship between the population size-standardised total number of child deaths as a function of national poverty.

Figure 6. Relationship between population size-standardised child mortality (0–1 year old; square-root scale) and national-scale poverty (logit proportion of total population). Also shown are the equivalent linear scales for the *x* (upper axis) and *y* axes (right axis).
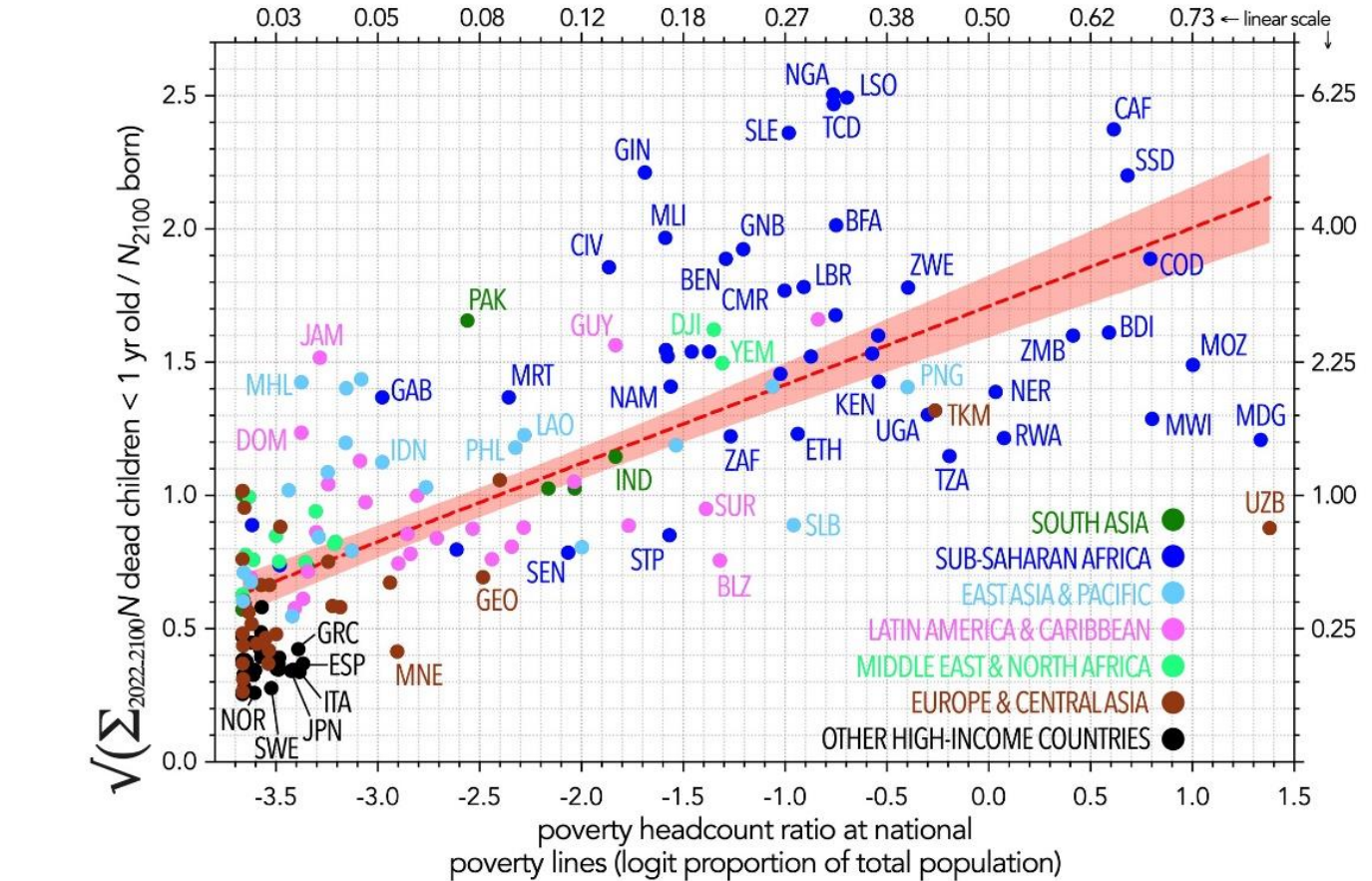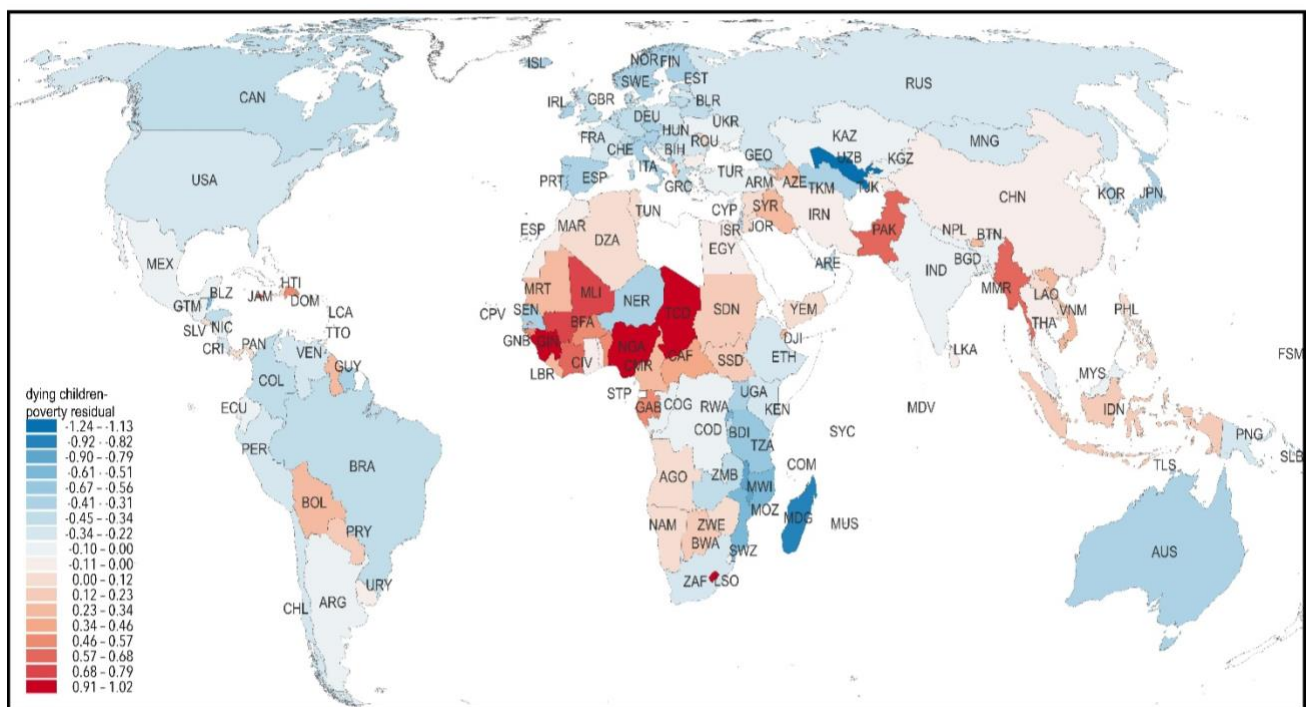

Country codes shown: BDI = Burundi, BEN = Benin, BFA = Burkina Faso, BLZ = Belize, CAF = Central African Republic, CIV = Côte d'Ivoire, CMR = Cameroon, COD = Democratic Republic of Congo, DJI = Djibouti, DOM = Dominican Republic, ESP = Spain, ETH = Ethiopia, GAB = Gabon, GEO = Georgia, GIN = Guinea, GNB = Guinea-Bissau, GRC = Greece, GUY = Guyana, IDN = Indonesia, IND = India, ITA = Italy, JAM = Jamaica, JPN = Japan, KEN = Kenya, LAO = Laos, LBR = Liberia, LSO = Lesotho, MDG = Madagascar, MHL = Marshall Islands, MLI = Mali, MNE = Montenegro, MOZ = Mozambique, MRT = Mauritania, MWI = Malawi, NAM = Namibia, NER = Niger, NGA = Nigeria, NOR = Norway, PAK = Pakistan, PHL = Phillipines, PNG = Papua New Guinea, RWA = Rwanda, SEN = Senegal, SLB = Solomon Islands, SLE = Sierra Leone, SSD = South Sudan, STP = Sao Tome and Principe, SUR = Suriname, SWE = Sweden, TCD = Chad, TKM = Turkmenistan, TZA = Tanzania, UGA = Uganda, UZB = Uzbekistan, YEM = Yemen, ZAF = South Africa, ZMB = Zambia, ZWE = Zimbabwe

As hypothesised, there is a strong relationship ($R^2 = 0.54$) between the number of projected child deaths and

poverty (Fig. 6). However, the more interesting outcome of this relationship is where individual countries sit relative to this expected positive relationship — countries with high positive residuals (above the line of best fit) are predicted to experience many more child deaths over the remainder of the century than their poverty or population size would otherwise predict, whereas those countries with negative residuals (below the line of best fit) are predicted to have far fewer child deaths than their poverty or population size would otherwise predict. Countries such as Nigeria, Chad, Lesotho, Guinea, Sierra Leone, Central African Republic, South Sudan, and Pakistan have much higher predicted child deaths than their poverty or population sizes would otherwise predict. In contrast, countries like Uzbekistan, Mozambique, Madagascar, Rwanda, Malawi, and Tanzania have much fewer (visualised spatially in Fig. 7).

Figure 7. World map of the residuals from the relationship in Fig. 6 – the redder the colour, the higher the poverty- and population-standardised child mortality; the bluer, the lower the poverty- and population-standardised child mortality (see residuals in Fig. 6).


Country codes shown: AGO = Angola, ARG = Argentina, ARE = United Arab Emirates, ARM = Armenia, AUS = Australia, AZE = Azerbaijan, BDI = Burundi, BEN = Benin, BFA = Burkina Faso, BGD = Bangladesh, BIH = Bosnia and Herzegovina, BLR = Belarus, BLZ = Belize, BOL = Bolivia, BRA = Brazil, BTN = Bhutan, BWA = Botswana, CAF = Central African Republic, CAN = Canada, CHE = Switzerland, CHL = Chile, CHN = China, CIV = Côte d'Ivoire, CMR = Cameroon, COD = Democratic Republic of Congo, COG = Congo, COL = Colombia, COM = Comoros, CPV = Cabo Verde, CRI = Costa Rica, CYP = Cyprus, DEU = Germany, DJI = Djibouti, DOM = Dominican Republic, DZA = Algeria, ECU = Ecuador, EGY = Egypt, ESP = Spain, EST = Estonia, ETH = Ethiopia, FIN = Finland, FRA = France, FSM = Micronesia, GAB = Gabon, GBR = United Kingdom, GEO = Georgia, GIN = Guinea, GNB = Guinea-Bissau, GRC = Greece, GTM = Guatemala GUY = Guyana, HUN = Hungary, HTI = Haiti, IDN = Indonesia, IND = India, IRL = Ireland, IRN = Iran, ISL = Iceland, ISR = Israel, ITA = Italy, JAM = Jamaica, JOR = Jordan, JPN = Japan, KAZ = Kazakhstan, KGZ = Kyrgyzstan, KEN = Kenya, KOR = Korea, LAO = Laos, LBR = Liberia, LCA = Saint Lucia, LKA = Sri Lanka, LSO = Lesotho, MAR = Morocco, MDG = Madagascar, MDV = Maldives, MEX = Mexico, MHL = Marshall Islands, MLI = Mali, MMR = Myanmar, MNE = Montenegro, MNG = Mongolia, MOZ = Mozambique, MRT = Mauritania, MUS = Mauritius, MWI = Malawi, MYS = Malaysia, NAM = Namibia, NER = Niger, NGA = Nigeria, NIC = Nicaragua, NOR = Norway, NPL = Nepal, PAK = Pakistan, PAN = Panama, PER = Peru, PHL = Phillipines, PNG = Papua New Guinea, PRT = Portugal, PRY = Paraguay, ROU = Romania, RUS = Russia, RWA = Rwanda, SDN = Sudan, SEN = Senegal, SLB = Solomon Islands, SLE = Sierra Leone, SLV = El Salvador, SSD = South Sudan, STP = Sao Tome and Principe, SUR = Suriname, SWE = Sweden, SWZ = Eswatini, SYC = Seychelles, SYR = Syria, TCD = Chad, THA = Thailand, TKM = Turkmenistan, TTO = Trinidad and Tobago, TUR = Türkiye, TZA = Tanzania, UGA = Uganda, UKR = Ukraine, URY = Uruguay, USA = United States, UZB = Uzbekistan, VEN = Venezuela, VNM = Vietnam, YEM = Yemen, ZAF = South Africa, ZMB = Zambia, ZWE = Zimbabwe

Averaging the residuals of the relationship shown in Fig. 6 by region indicates which regions will have the highest burden of child mortality after poverty and population size are taken into account (Fig. 8). This

summary analysis indicates that sub-Saharan Africa is still the region with the greatest burden of child mortality. Latin America/Caribbean is a region with an approximately expected burden of child mortality, whereas other high-income nations and Europe/Central Asia will have fewer child deaths than otherwise expected (Fig. 8).

Figure 8. Mean residuals (across countries) of the relationship between population size-standardised child deaths predicted from 2022 to 2100 and national poverty (see Fig. 6) by major global region. Blue (mean negative residual) bars indicate the regions with lower-than-predicted child deaths, and red bars (mean positive residual) indicate regions with higher-than-predicted child deaths.
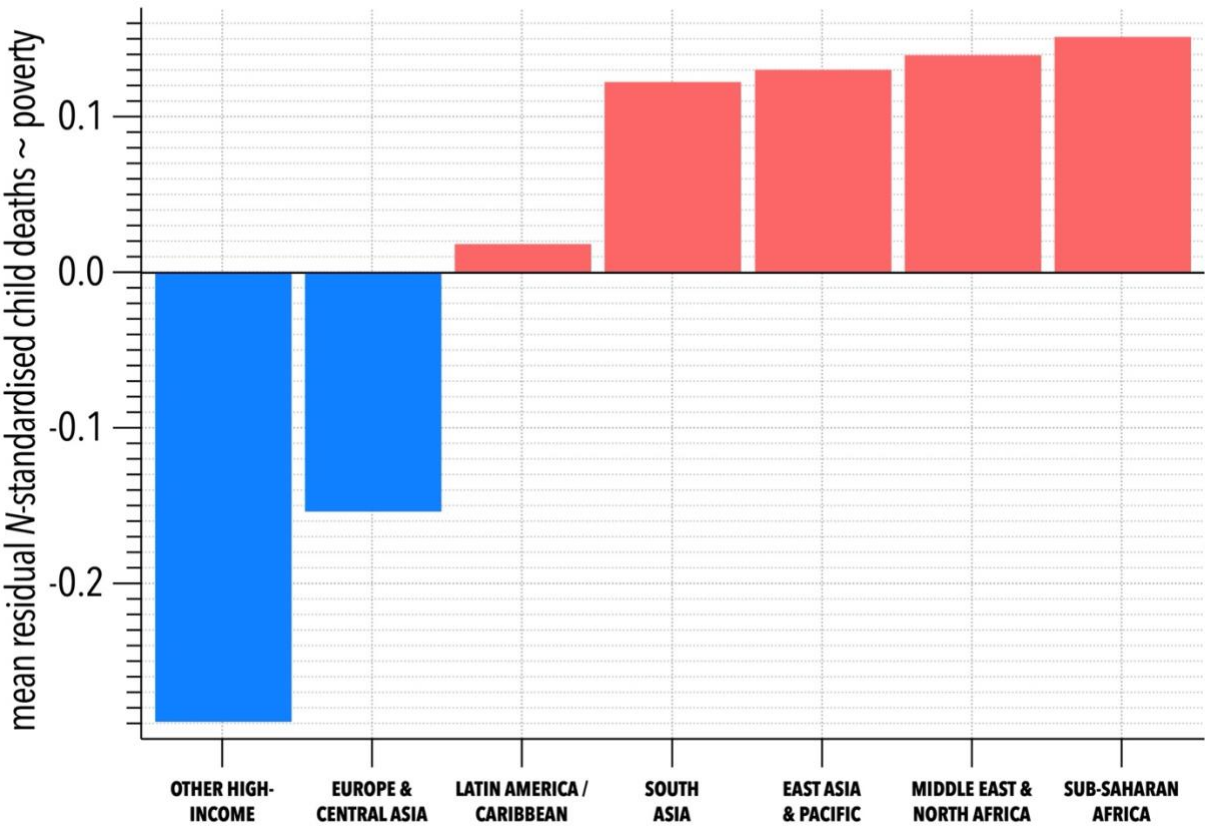
Assessing the effects of overpopulation on future children

To determine the risks for future children and provide the opportunity to counter serious threats, accurate information on the outlook for their health and wellbeing is essential. For assessing risk, infant mortality is an important index of a society's ability to protect children's health. To produce projections of infant mortality from 2022 to 2100, the United Nations used their own *Medium* fertility variant for population growth (22) and fitted a smoothed line to previous data on infant mortality for each country, and then extrapolated this to 2100 (8). This methodology assumes a business-as-usual expectation that the pattern of decreasing infant mortality over the last few decades will continue unchanged into the future. It relies on retrospective mortality data and does not consider the increasing risks to infants as population rises and the expectation of increasing risks to children as climate change worsens (2, 44, 117). Hence, the United Nations' approach will inevitably underestimate the number of children who will die this century.

Although United Nations' data on infant mortality rates show a continuing decline to 2021 under the *Medium* projection variation (169), the time when improvements to health are reversed by climate change and overpopulation might have already arrived, given recent evidence suggesting that infant mortality is already

14

469 increasing in countries from several different regions. For example, recent increases have been observed in
470 both the USA and France (170, 171), as well as in India, Madagascar, Cambodia, Nepal, and the Philippines
471 (172).
472

Access to quality family planning benefits children's health
474 A proven approach to reducing fertility is to give all men and women access to free, voluntary, culturally
475 sensitive, locally appropriate, quality family-planning services. Such access allows prospective parents to choose
476 the size of their family and is considered a human right (16). Even though this is part of the United Nations'
477 Sustainable Development Goal 3.7 (173) and has been supported by the World Health Organization (16, 174),
478 the unmet need has received less attention than climate change. According to a World Bank report, the
479 intervention of meeting 90% of the unmet need for contraception alone in 2015 would have reduced annual
480 global births by 28 million and averted 440,000 neonatal and 473,000 child deaths (175). Because countries with
481 unmet contraception needs (176) are those with the highest fertility rates and the highest population growth
482 (177), these numbers will increase over coming decades. With the likely decline in health as continuing rapid
483 population growth in these countries outstrips resource availability, the true increase in neonatal and child deaths
484 will be much greater. Reduced fertility will therefore help to protect future children from early death or a life of
485 ill health.
486

487 Several factors beyond access to quality family planning are associated with lower fertility rates. These include
488 higher maternal education (178), lower infant mortality (46), greater socio-economic prosperity (179), and lower
489 religious adherence (180). Although these associations have often been interpreted as causal (178, 181), there are
490 many potential confounding interactions. For example, women who are more educated are likely to be more
491 prosperous than those who less-educated, and the relationship between high infant mortality and high fertility
492 can be bi-directional in causality, because high infant mortality can increase fertility, whereas higher fertility can
493 increase infant mortality (182-184). The evidence that fertility declines as soon as quality family planning is
494 available is extensive, with poignant examples from Bangladesh (185-187), Kenya (189), and Iran (189, 190). At
495 the country scale, lower fertility is related to lower infant mortality, lower household size, and increased access
496 to contraception, each of these being more important than either female education or religious adherence (46). In
497 short, efforts to increase access to family planning will counter the self-facilitation feedback of increasing
498 population on increasing infant and child mortality in low- and middle-income countries.
499

500 There have been no modelled projections of the effects of various scenarios for increasing the availability of
501 family planning in countries with unmet needs of contraception on childhood deaths, while simultaneously
502 considering resource and nutrition limitation and climate change. Demonstrating the importance of this issue to
503 the health of future children would provide compelling evidence for a much greater focus on implementing the
504 introduction of high-quality family planning across the globe to reduce deaths and suffering in future
505 generations of children.
506

Future prospects for children
508 We have provided the first summary of the evidence that overpopulation is adversely affecting children and that
509 further increases in population will have increasingly serious consequences for children in the future unless
510 substantial measures are taken to reverse population growth. Our analyses emphasise that most children born this
511 century will be in sub-Saharan Africa and Central/South Asia where malnutrition is already high, the capacity to
512 increase crop yields is low, and the impacts of climate change on child health are high and already contributing
513 to infant mortality. Low-income nations have the fewest resources to protect higher numbers of children from
514 the effects of overpopulation and the deteriorating climate. We also emphasise that the need to reduce population
515 to protect future children must include wealthy, high-consumption nations. A global reduction in population is
516 essential if the future of prosperous and healthy human societies on this planet is to be secured. If we want to

be responsible global custodians, respecting the rights of current and future children to a healthy life is essential. Transferring this message broadly could reduce unnecessary deaths in infants and children and assist in mitigating environmental damage. More discussion of future child health would also assist in finding ethical means to bend down the trend in global population. The need for high-quality and wide-ranging research to determine what is needed to provide a healthy environment for future children is one of the greatest unmet needs for global health research.

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Supplementary Information

Appendix 1. Literature review of population density, overpopulation, and child health outcomes

A PubMed search on 8 April 2024 using the terms "population density" OR "overpopulation" & "child health", between 2015 and 2024, yielded 84 results. After screening the full papers, we identified 40 papers showing an effect of population density on child-health outcomes. We discuss these reported effects of population on pregnancy, infants, children specifically, and children as part of the larger population.

Three papers assessed the impacts of population density on pregnancy outcomes. In the developing region of Tibet, low population density was directly associated with low healthcare coverage and poor maternal outcomes during pregnancy (1). However, this outcome was directly related to access to healthcare rather than population density itself. In the high-income region of North Carolina, USA, higher population density was correlated with lower rates of teenage pregnancy; however, ethnicity, poverty, and education had larger effects on rates of teenage pregnancy and the reasons why population density influenced teenage pregnancy was not discussed (2). A study of pregnant women in New York, USA, reported no statistical evidence for an association between SARS-CoV-2 infection and population density (3).

We found three papers examining infants. A Tanzanian study investigating the effects of urbanisation on neonatal and perinatal mortality revealed an increased risk with increasing population density, independent of travel time to the nearest hospital (4). A study from Ghana found higher population density was correlated with reduced neonatal mortality, likely associated with increased maternal health coverage (5). The third study from Canada assessed fungal contamination of human milk, finding lower contamination in lower-density populations (6). Another 26 studies reported effects of population density on child-health outcomes, including mortality and overall health, nutrition outcomes, factors associated with safe drinking-water, sanitation and hygiene, vaccination, and vector-borne diseases, among others.

Among 172 low- and middle-income countries, higher population density amplified childhood stunting and mortality by increasing the negative influence of poor sanitation (7). Increasing population density was negatively associated with under-five mortality in Ethiopia, with this effect likely related to healthcare coverage (8). A composite child health index derived for countries across Africa revealed declining child health outcomes were associated with increasing household size, a proxy for population density (9).

Prevalence of childhood stunting (10), wasting (11), and being underweight (12) in Ethiopia declined with increasing population density, which was related to healthcare coverage and availability rather than population itself. Adolescent height was positively correlated with higher population density in China, likely reflecting lower poverty and more accessibility to health services (13). In contrast to the undernutrition studied in low-

income countries, childhood obesity is more commonly studied in high-income countries. Lower population density was associated with higher body mass index in Norway, attributed to lifestyle differences in urban *versus* rural areas (14). Conversely, in a paediatric cohort in Philadelphia, USA, increasing population density was correlated with a lower 'greenness' score that contributed to increases in body-mass index (15).

Improved water, sanitation, and hygiene improve child health; however, high population density and unplanned development of water supply and sewerage system can cause high enteric disease in children in Bangladesh (16), with the effects of good sanitation reducing diarrhoea amplified as population density increases (17). A global review of childhood diarrhoea due to *Cryptosporidium* reported a positive correlation with population density (18). Overcrowding was identified as a risk factor for soil-transmitted helminth infection in children in the Philippines (19).

Childhood vaccination coverage was positively associated with population density in Ethiopia (20, 21) and Pakistan (22). Again, the common theme of higher population density related to healthcare coverage in lower-income countries was the mechanism of improved child health, rather than a reflection of population itself. Similarly, compared to regions with low population density in Senegal, the probability of complete immunisation was higher in regions with intermediate population density, but higher population densities did not increase vaccination coverage further (23), indicating the existence of a minimum threshold of healthcare coverage for improved immunisation outcomes in children, rather than population density alone affecting this outcome.

Two papers reported the effects of population density on dengue infection in children. A study in Thailand found that transmission was positively correlated with population density (24), and in Indonesia higher odds of seropositivity to dengue was associated with higher population density (25).

There are several other reported child-health outcomes related to population density. In low-income countries or socially disadvantaged communities, higher population density was associated with poorer outcomes for children, while the opposite effects have been reported in high-income settings. In India, higher population density correlated with increased risk of being predisposed to diabetes (26). In the slums of Haiti, high population density was linked to high incidences of respiratory and gastrointestinal illness in children under five years of age (27). In a disadvantaged community in the USA, high population density was linked to increased crime and low education, and resulted in lower cognitive abilities, higher body-mass index, and more sleep disorders in children (28).

The following studies from high-income countries reported beneficial effects of higher population density on child health outcomes. In England, higher population density was associated with a slightly lower rate of hospital admissions for children with bronchiolitis (29). A Western Australian study on child development

reported lower odds of physical vulnerability were associated with increased residential density (30). In Ontario, Canada, higher population density decreased the odds of binge-drinking in adolescents (31). In Finland, higher incidence rates of paediatric irritable bowel disease were associated with regions with lower density of child population (32).

Eight other studies reported the impacts of population density on population health, including children. Higher population density is a risk factor for disease transmission globally, including for zoonotic infections (33) and COVID-19 (34), with transmission worse in slums with a higher proportion of young people. In India (35) and Indonesia (36), high population density increased the risk of dengue infection, which disproportionately affects children over five years of age. Typhoid outbreaks in Malawi were associated with increasing population density (37). In China, another consequence of higher population density is more air pollution and the resultant higher burden of disease via more people being exposed to that pollution (38). In contrast, lower population density was linked to lower risk of developing irritable bowel disease in Canada, with the association strongest in young children and adolescents (39). In Haiti, higher population density was one of the correlates of seeking conventional treatment when sick (40), likely a consequence of reduced barriers to healthcare rather than a direct effect of population size.

Overall, the effects of population on child health outcomes vary greatly depending on a country's relative income. High population density in lower-income countries is linked to both negative and positive child health outcomes; however, every positive child health outcome was facilitated by increased access to healthcare rather than a direct benefit from population density itself. Those directly related to population density show increasing population density worsened child health in lower-income countries. Because most future children will be born in developing countries (see main text), there is a disproportionate negative effect of higher population densities on most children worldwide. Population density also had mixed effects on child health in higher-income countries; however, it appears that these children are buffered from many of the worst health outcomes.

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