How underestimating the risks of population pressure endangers the health and lives of current and future children

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Methodology

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. We found three papers examining infants. 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. Eight other studies reported the impacts of population density on population health, including children. All studies and reports included in this evidence review will be found on the references on page 28.

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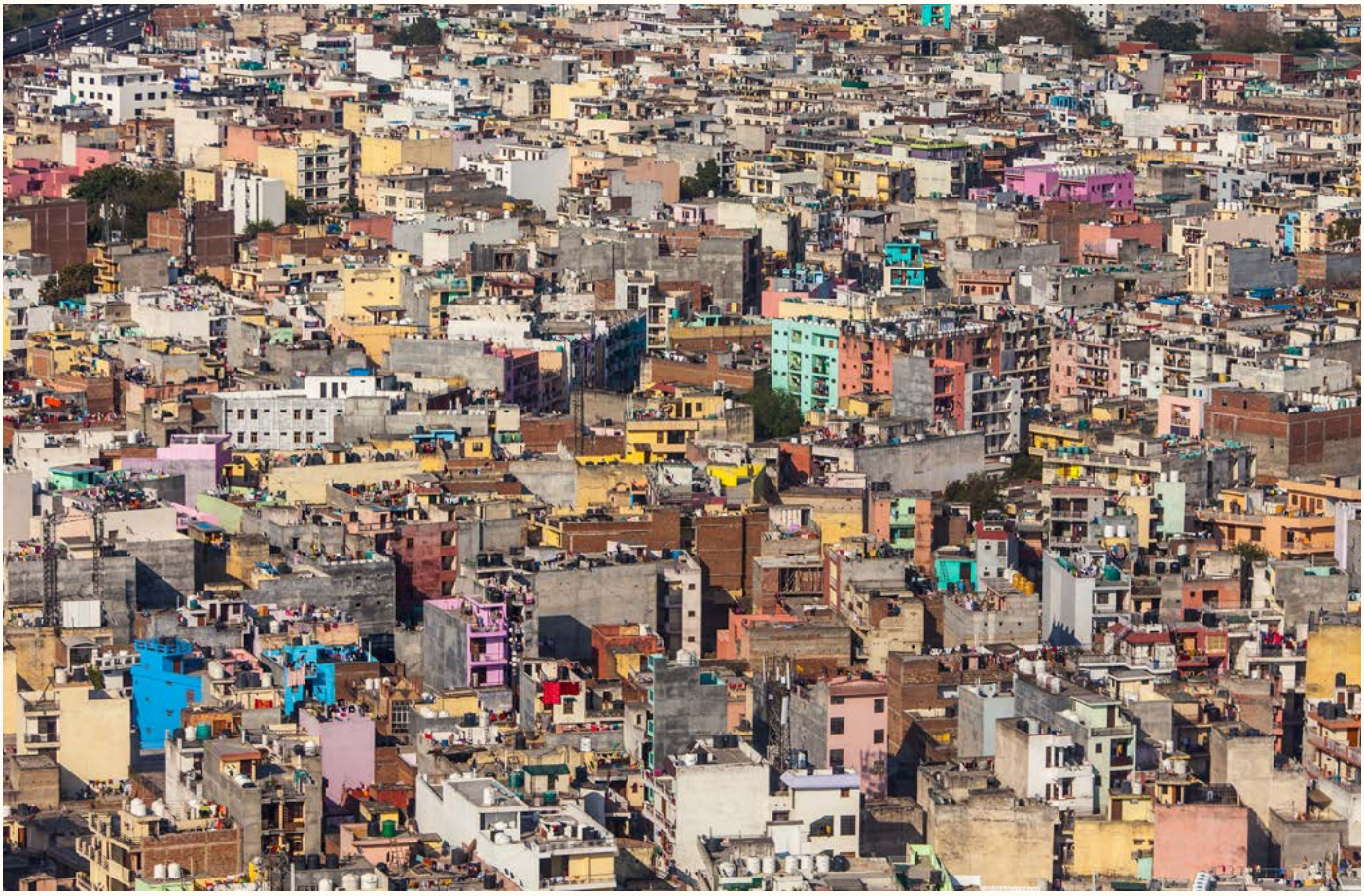
Fragile Futures

How underestimating the risks of population pressure endangers the health and lives of current and future children



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Fragile Futures Executive Summary

Infant mortality rates have been declining, more children survive beyond the age of five than ever before, following on from years of hard work by the global health community. Success around the Sustainable Development Goal (SDG 3.2) to end preventable deaths of newborns and children under-five years of age, is a cause for celebration. Since 1990, the total number of under-five deaths worldwide has declined from 12.8 million to 4.9 million in 2022.[i]

Published projections on infant and child mortality by the United Nations estimate that they will continue to follow this downwards trend. However, United Nations projections are based on the extrapolation of past demographic data with a 'business-as-usual' outlook (8) and do not account for the effects of climate change-driven environmental destruction or increasing population pressure on child survival. In this report, we summarise the evidence that population pressure and climate change will worsen children's health and wellbeing this century, resulting in the world witnessing a reversal in the rate of under-fives survival.

Most children this century will be born in the poorest regions

Whilst declining birth rates may dominate news headlines in the Global North, regions in the Global South are still experiencing rapid population growth. According to the United Nations' population projections, between 9 and 14 billion children will be born between now and the end of this century (162). The region with the highest number of births is Sub-Saharan Africa, where between 3 to 5 billion children are predicted to be born by 2100.

Sub-Saharan Africa is by far the poorest region in the world, where 22 of the 48 countries therein are classified as 'low-income', it also includes 22 of the world's 26 poorest countries (165). The region where the highest number of children will be born this century is by far the poorest, and as a result also carries one of the world's highest rates of under-five mortality. In 2018, Sub-Saharan Africa recorded an under-five mortality rate of 78 deaths per 1000 live births, compared to an average of 39 deaths per 1000 live births globally.[ii] Therefore, the region where the majority of the world's children are being born, is also the region where most children are dying before their fifth birthday. Whilst medical and humanitarian advances have helped to reduce child mortality in the region, Sub-Saharan Africa still carries an inequitably high burden of child mortality.

High infant mortality drives high fertility and perpetuates poverty

There is a direct and proportional relationship between high child mortality rates and high fertility rates (184-186). In short, high under-five mortality rates cause high fertility rates, defined as when a woman has five or more births during her reproductive years. When children are less likely to survive to adulthood, couples tend to have larger families as a form of "insurance" against the tragically high mortality rates that could reduce the size of their families below their desired number (184-186). High fertility rates are one of the main drivers of rapid population growth, resulting in stalled development and persistent poverty in low-income countries. To quote the United Nations Department of Economic and Social Affairs, "*high levels of fertility, rapid population growth and widespread poverty often go hand in hand, trapping countries, communities and individuals in a vicious cycle.*"[iii]

Large family sizes in low-income communities result in poverty traps as families are unable to provide sufficient resources for each child. Often, children are not able to attend school: this particularly affecting young girls, who can also end up being sold for dowries as child brides. Child marriages often result in underage pregnancies with serious health complications for young mothers and infants; stillbirths and newborn deaths are 50% higher in mothers

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under the age of 20.[iv] If young children, especially girls, are unable to access quality education then this perpetuates the cycle of poverty down the generations.

What applies to families, also applies to nations. In low-income countries, providing jobs, infrastructure, health services and education to a rapidly growing population is an increasingly difficult challenge that strains the ability of public services to function. If a country's economy cannot keep up with the rising number of people to employ youth productively this causes high levels of unemployment, stalling economic development for low-income countries.

It is well-established that poverty is one of the main causes of under-five mortality rates, and as high child mortality causes higher fertility rates, so too does it perpetuate this negative cycle of more children being born into and trapped in poverty. Our research shows that accounting for relative poverty among nations, Sub-Saharan Africa, the Middle East and North Africa, East Asia & the Pacific and South Asia, all will have a higher-than-expected burden of child mortality, not shown in current projections.

Most children will be born in climate vulnerable regions

The climate crisis is a global issue, yet most climate models predict it will have a more destructive impact on lower-income countries in the Global South due to having fewer resources to adapt or respond to natural catastrophes. The worst health effects of climate change will be felt by children, particularly children in low- to middle-income countries. Children are most vulnerable to climate health effects due to a combination of physiological and social conditions. The Global South will carry the highest burden of children affected by climate change, as there will be more children born in these regions, and because of the increasing number of vulnerable children born into low-income communities with the least resources to be resilient to climate effects.

It has been identified that climate change will cause an average 60% increase of preterm births, due to hotter temperature exposure during pregnancy.[v] Preterm births are a contributor to higher rates of infant mortality, and the effects of a preterm birth can result in long-term health problems that can shape a child's entire

life, including neurological impairment, stunted growth, and other disorders. The risk of preterm birth is already higher in low- and middle-income countries and this will increase due to more frequent and persisting heatwaves, which will have devastating long-term effects on women and children's health.

Children's respiratory health is particularly vulnerable to climate change. Globally, high temperatures increase the risk of respiratory disease in children, and high humidity increases the prevalence of childhood pneumonia. Climate change has also been associated with more air pollution exposure, increasing cases of asthma, eczema, and allergies in young children. Additional studies also report potential health effects on children that include heat stroke, organ failure and mental health problems amongst others.

Whilst children in the Global North will also be affected by climate change, higher-income countries with more integrated health infrastructure will be better able to adapt and shield children from the worst effects. In addition, nations in the Global North will not face the same amount of pressure on health infrastructure from rapidly growing populations as will occur in regions in the Global South.

The most climate vulnerable regions are low-income nations with the fewest resources to adapt, experiencing high rates of population growth that will cause further resource strain. The countries where the climate risk is highest are where the greatest numbers of children are being born, and unless concerted action is taken, climate health effects will most disproportionately impact these vulnerable children and there will be a corresponding increase in under-five mortality rates. The world must care for all its children and it's vital that we recognise the need to act to both improve climate resilience in vulnerable regions and address population growth through the positive solutions available.

The world will struggle to feed future generations

The United Nations' World Population Prospects most likely scenario (called the medium variant) is for the world to reach a population of 10 billion people by 2061.

Children are disproportionately affected by food insecurity and malnutrition, which can affect their growth and development, and often presents as physical stunting in young children. 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 also compromises the immune system resulting in higher mortality rates from infectious diseases. Malnutrition in areas of Sub-Saharan Africa is also a cause of worse educational performance. If children lack the food they need, they struggle to learn.

The consequences of food insecurity are already being seen with increases in malnutrition and stunting in young children. 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 above 30% in low-income countries (111). Their reports have expressed concern that Sustainable Development Goal 2.2, to end all forms of malnutrition, will be missed.

The oncoming crisis for children's health globally this century is that there will be increasing numbers of children to feed whilst crop yields decline due to climate breakdown. Most children born this century will be in Sub-Saharan Africa and Central and South Asia where malnutrition is already high, the capacity to increase crop yields is low, and there is already high infant mortality. Continued rapid population growth in these regions will only increase pressure on food systems, resulting in further food insecurity and widespread malnutrition, with the vulnerable children born into these situations suffering from the harshest effects.

We must address global inequities and climate injustices

It's a known fact that high-income countries are historically responsible for the greatest volume of greenhouse gas emissions causing anthropogenic climate change. In addition, the high-consumption lifestyles of those in the Global North contribute far more to greenhouse gas emissions than low- to middle-income countries, with half of consumption-related emissions being generated by only 10% of people globally. Lower-income nations have contributed the least to climate change and have the least resources to combat climate-related natural disasters. This is the great climate injustice, that those who have contributed the least will deal with the most severe consequences.

We emphasise that countries in the Global North must take responsibility for their historic and continued high emissions, with action to reduce their emissions and consumption of resources, and to provide aid and reparations to the most climate-affected countries.

We also call for the challenges posed by population dynamics in the Global South to be recognised, and to not avoid addressing population growth in the fastest-growing regions, especially when the solutions to do so are rooted in women's empowerment, education, and community leadership.

Globally, children born in low- and middle-income nations will be the most burdened, with the worst health and well-being outcomes, and will comprise the majority of the world's children. In light of this, it's imperative that we act now to assist low to middle-income countries with achieving a demographic transition faster, so they can develop sustainably, improve their climate resilience, and safeguard the futures of billions of children.

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Increasing child mortality rates are already upon us

Evidence suggests that infant mortality rates are already increasing in several different regions, as the effects of climate change and population pressure take hold (171-173). Our report identifies that recent increases in child mortality rates have been observed in both high-income countries such as the United States and France, and more predominantly in low- to middle-income countries including India, Madagascar, Cambodia, Nepal, and the Philippines.

Family planning to empower women and improve children's health

Healthy mothers mean healthy children; ensuring women can choose to space their pregnancies, and with their partners determine the size of their families, is vital to improve maternal health and survival rates for newborns and young children. Shortfalls in sexual and reproductive healthcare funding have meant an estimated 257 million women of child-bearing age worldwide still face an unmet need for family planning.[vi]

Even though ending the unmet need for family planning is part of the United Nations' Sustainable Development Goals, with SDG 3: Good Health and Well-being and SDG 5: Gender Equality, it has received relatively little attention. According to a World Bank report, satisfying 90% of the unmet need for contraception in 2015 would have averted 440,000 neonatal and 473,000 child deaths (176).

The importance of universal access to family planning cannot be understated. When individuals are empowered to choose smaller families, they can invest more resources and time in each child, improving health outcomes, reducing infant and child mortality, and benefiting the well-being of families and entire communities. In many ways, lower fertility rates observed in developed countries are an indicator of female autonomy, empowerment, and equity. But women in low- and middle-income countries face multiple socio-economic barriers to their family planning needs, as do an increasing number of women in high-income countries when laws and politics encroach on individual rights.

There is already insufficient support to address the shortfalls in targets to achieve SDG 3 and

SDG 5, and significant challenges remain, particularly regarding inequalities in healthcare access and women's lack of representation in leadership roles. With recent changes in global leaders, such as the incumbent Trump administration, meaning there is also now more restrictions to sexual and reproductive healthcare provision.[vii] Therefore, it's urgent that we emphasise the wider impacts that lack of sexual and reproductive healthcare funding will have on children's health and wellbeing to gain more active support from policymakers to prioritise SDG 3 and SDG 5 targets.

A woman without access to safe, modern contraception or with her sexual and reproductive rights restricted by the state, lacks the power to be in control of her body, her fertility, and her future. Investing in quality health care for all, including universal access to family planning, is necessary to improve the lives of millions of women and children.

Invest in girls' education to improve children's health

Education is a basic right and a necessary tool for development, yet due to persisting gender inequality and patriarchal cultural norms in many low- to middle-income countries approximately 119 million girls remain out of school[viii], with this number set to increase due to population growth.

Investing in female education is crucial to ending gender inequality, as it enables women to develop careers to become economically independent and empowers them to be community leaders at the forefront of climate resilience. Educated women typically choose to have smaller families, have healthier children and are healthier themselves.

Greater investment in quality education for all is key to alleviating poverty, improving climate resilience, and ending global population growth which can pave the way for more sustainable development for the benefit of people and the planet.

"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."

Population growth is a driver of climate change

This report has emphasised that both climate change and population pressure will have significant impacts on children's health and will cause a rise in under-five mortality rates throughout the rest of this century. Whilst it may be thought that climate change and population growth are separate issues and therefore focus should be placed on one or the other, it's important to outline that population growth is one of the main drivers of climate change. The Intergovernmental Panel on Climate Change's 2022 full report stated, "*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*".[ix] Though this fact is not as widely known as it should be as it was not included in the summary for policymakers.

We are sabotaging the futures of all the children yet to be born who will have to deal with the consequences of climate breakdown. Unless we act now to bring humanity back within sustainable ecological boundaries. This can be done. Fortunately, solutions are at hand and are extremely effective. By achieving a more sustainable population size through positive, ethical, and choice-based means, such as ending unmet need for family planning, ensuring quality education for all, and investing in more female-led leadership in communities. In addition to transitioning away from growth-focused to more circular economies to reduce our resource demand. In these ways, we can give ourselves the opportunity to enhance the quality of people's lives that are already here and safeguard the futures of generations of children to come.

Underestimating the risks of population pressure endangers the health and lives of future children

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 comment (1-3) and many regional analyses, although only one analysis of its potential global magnitude (4). In contrast, the impact of human population pressure on current children and the fate of future children is rarely discussed (5-7) and 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 population pressure.

Authors

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"The number of children adversely affected by climate change will increase not only because there will be more children, but because of the increasing number of vulnerable children" **(114-116).**

The aim of our document is therefore to provide the first summary of the existing evidence that population pressure has already affected children's health. We then use published novel 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)

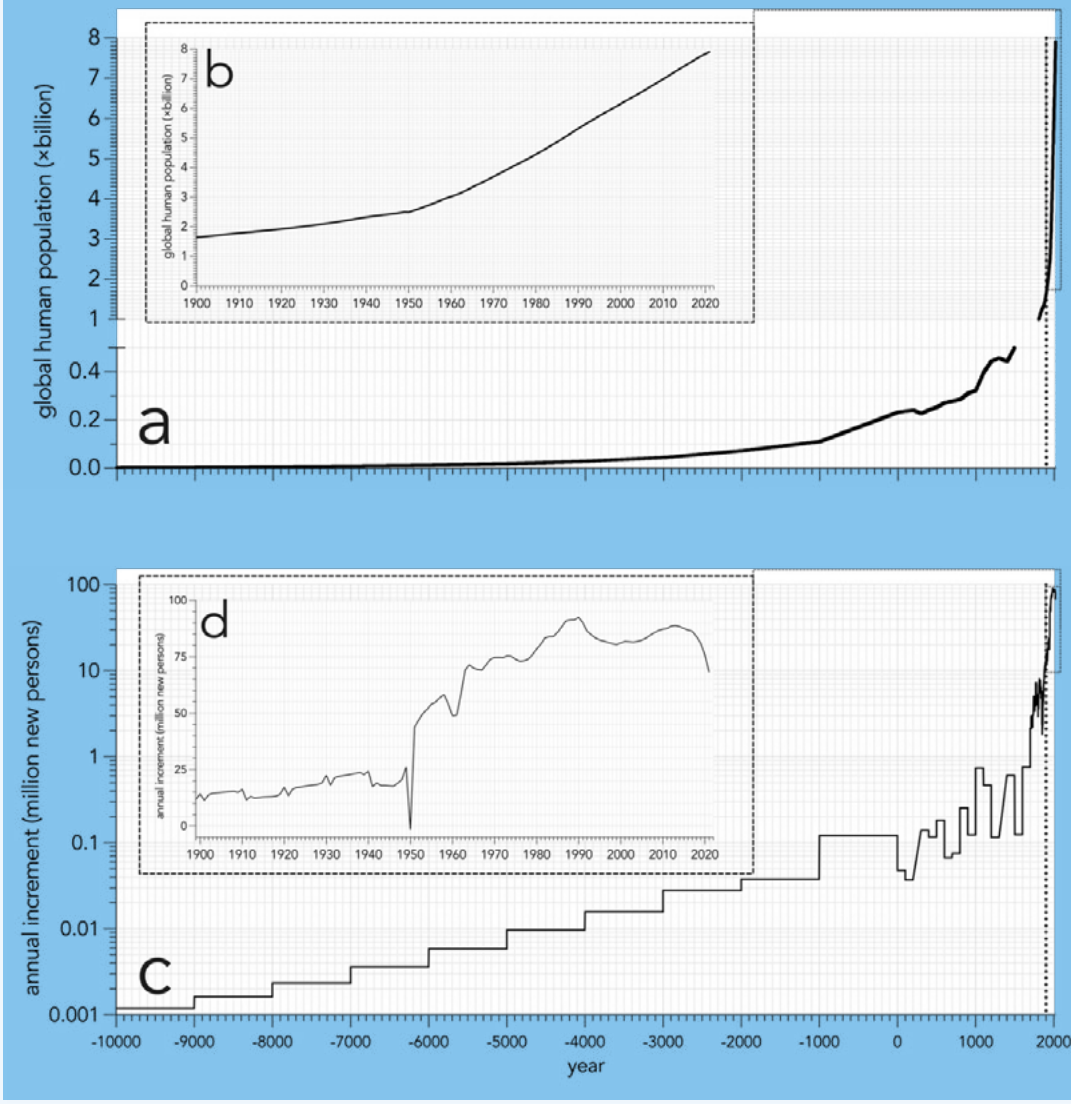


Figure 1:

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 observed that humans were taking around 60% more from their environment than the environment could sustain. With an increasing population, this figure 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).

Addressing inequity and global injustice 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 population pressure 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 and reverse population growth 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: "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 population pressure (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 change 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.

Population pressure 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 population pressure 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) PM2.5 (67).

Air Pollution and Infant Mortality

Higher population density directly correlates with higher rates of air population in cities.

The five African cities with the highest populations also have the highest concentrations of air pollution with a score of (particulate matter) PM2.5 (67).

Air pollution is a leading cause of childhood respiratory disease and infant mortality (69, 57). Air pollution in Africa caused an estimated 449,000 additional infant deaths in 2015 alone (57).

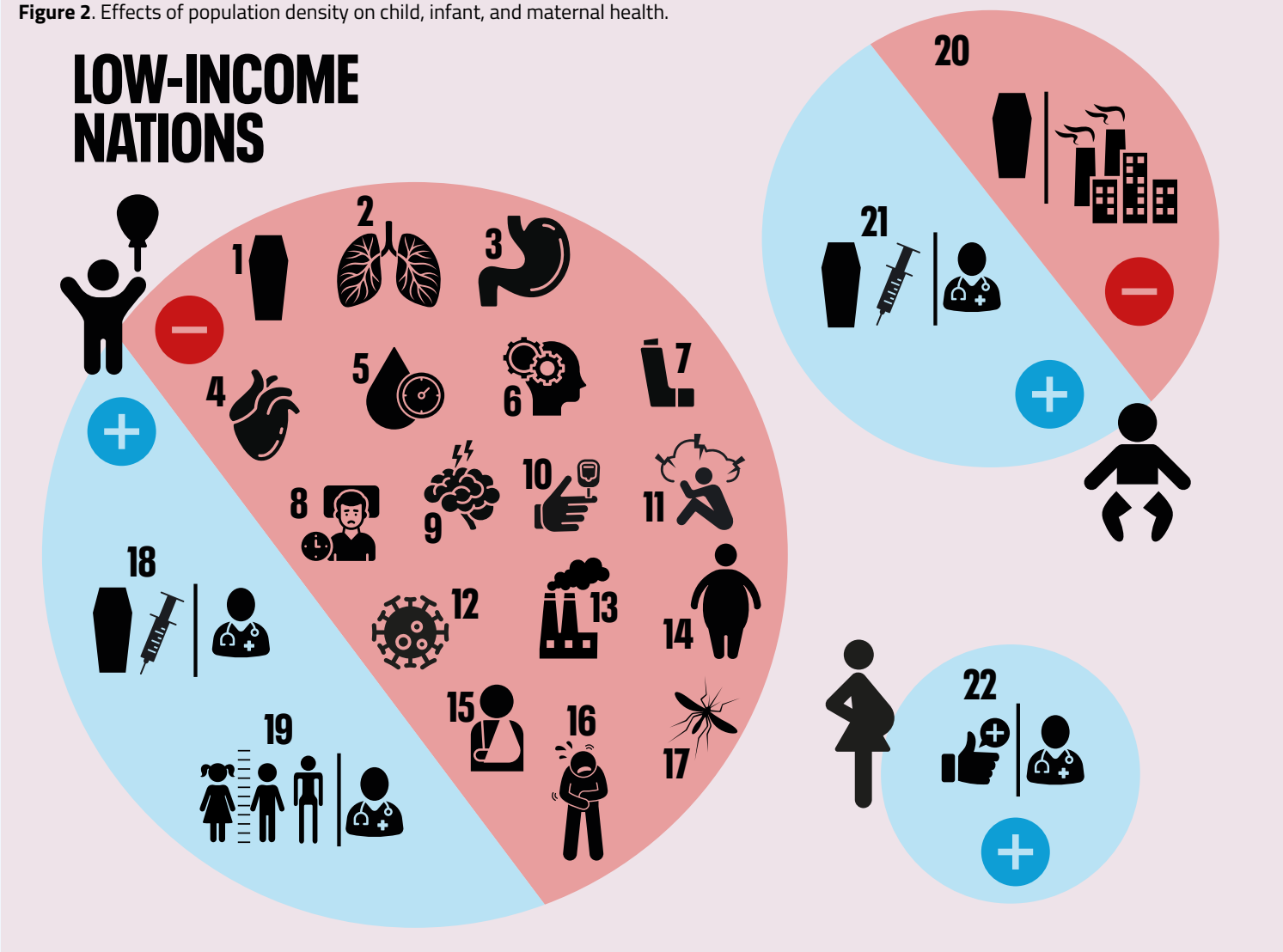
Mega-cities in India are among the most polluted cities in the world (68). The correlation between city size, population density, and air pollution is concerning, because air pollution is a major cause of childhood respiratory disease (69) and mortality (57). For each 10 µg m-3 increase in PM2.5, there 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, population pressure not only inhibits growth in children, but also increases the risks from breathing polluted air, most infectious diseases, and further pandemics.

To evaluate the relationships between population and child health in greater detail, we examined the published evidence for this. A literature search using the terms "population density" OR "population pressure" & "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 Figure 2 and the full review is available in Supplementary Appendix 1. There is evidence for many aspects of child health being affected 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.

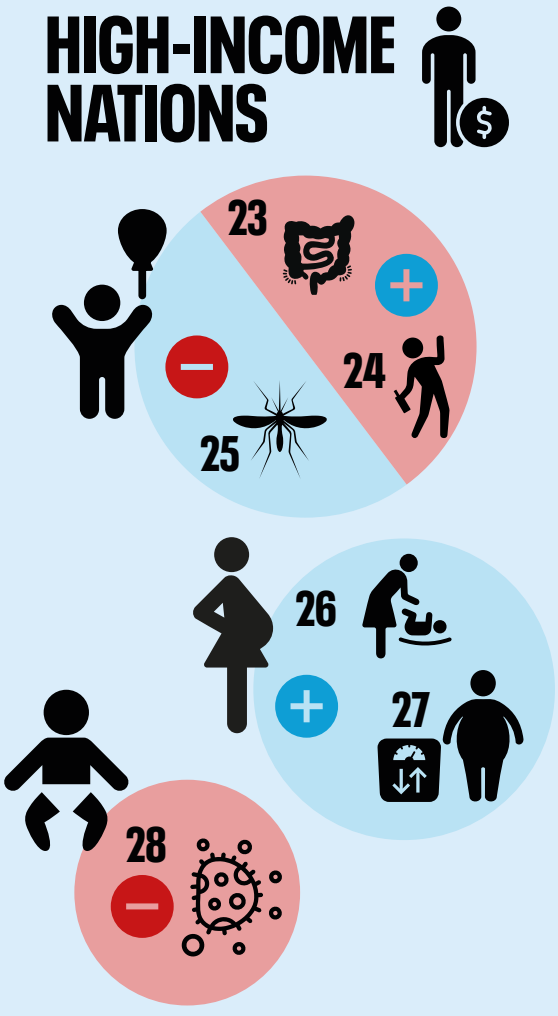
Figure 2. Effects of population density on child, infant, and maternal health.



Food Insecurity and Child Malnutrition

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, even though current food systems are unsustainable and inequitable (93, 96, 97). This increase will require 70 million hectares of additional land for planting crops, which will be lower-quality and erode biodiversity further (96, 39). But recent increases in undernourishment and the lack of additional arable land suggests that this aim can no longer be met (104). The number of undernourished people worldwide has been increasing, the latest estimates place the figure as high as 828 million (104).

This disproportionately impacts children's health. Malnutrition is a leading cause of physical stunting in children, the United Nations International Children's Emergency Fund estimated in 2022 that stunting was present in over 1 and 5 children globally. The World Health Organization has estimated that malnutrition is responsible for 45% of all childhood deaths in low- and middle-income countries (112, 113).



LOW-INCOME NATIONS

Negative effects (red) on children

1. ↑ mortality;
2. ↑ respiratory disease;
3. ↑ gastrointestinal/enteric disease;
4. ↑ cardiac issues;
5. ↑ hypertension;
6. ↓ cognitive ability;
7. ↑ asthma;
8. ↑ sleep disorders;
9. ↑ neurological problems;
10. ↑ diabetes;
11. ↑ psychological distress;
12. ↑ COVID;
13. diseases resulting from ↑ air pollution;
14. ↑ body mass index;
15. ↑ physical trauma;
16. ↑ typhoid;
17. ↑ vector-borne disease (e.g., dengue).

Positive effects (blue) on children

18. ↓ mortality & ↑ vaccination rate due to ↑ health care;
19. ↓ stunting/wasting/underweight due to ↑ health care.

Negative effects on infants

20. ↑ mortality due to ↑ urbanisation.

Positive effects (red) on infants

21. ↓ mortality & ↑ vaccination rate due to ↑ health care.

Positive effects (blue) on pregnant women

22. better maternal outcomes due to ↑ health care.

HIGH-INCOME NATIONS

Positive effects (blue) on children or adolescents

23. ↓ irritable bowel syndrome;
24. ↓ binge drinking.

Negative effects (red) on children

25. ↑ zoonotic disease transmission.

Positive (or equivocal) effects on pregnant women

26. ↓ teenage pregnancy
27. ↑ or ↓ body mass index.

Negative effects (red) on infants

28. ↑ fungal contamination of human milk.

Larger populations will adversely affect all future children

Despite high-income countries having more capacity to buffer children from future shocks, overcrowding can reduce access to green space and erode mental health and wellbeing (80-82), increase pre-term births (83), harm lung function (80), and lead to more respiratory diseases (84). Australia is an example of a high-income nation with a high net immigration rate; overall, its population growth exceeded 1.5% per year prior to the COVID-19 pandemic (85), and increased to 2.4% thereafter (86). Australia, like many resource-rich countries, relies on 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). To feed over 70 million people will be difficult given that Australia currently produces enough food to feed 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). A decline in Australia's food production would have serious global consequences, because it currently exports 72% of its food production (95) and its status as a major global food supplier would cease 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 suggests 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 consequent 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 worldwide (109), and economic resources to address these issues are most limited. Indeed, a study examined comprehensive data from every African country, including an environmental performance index to quantify environmental damage (110), to produce strong evidence that environmental degradation 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 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 figure 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 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 a driver of low educational status and economic damage (102), and both these outcomes will feed back to erode children's health (102).

Relationships between population pressure, climate change, and child health

The number of children adversely affected by climate change will increase not only because there will be more children, but because of the increasing number of vulnerable children (114-116). The latest Intergovernmental Panel on Climate Change report states with "very high confidence" that climate change has already harmed children's health, including most aspects of their physical and mental health (2, 117). Indeed, a deteriorating environment will have adverse effects on most organ systems (118) — rising ambient temperature and more frequent and intense heat waves, as well as worsening air pollution increase medical problems in children (119). The effects of climate change on children's health has been summarised recently in the first meta-analysis of all available published evidence (4). The greatest effects were in increases in preterm births and respiratory disease (4). Individual studies have also shown increases in preterm births (120-122), as well as respiratory infections (123, 124), asthma (114, 115, 125, 126), kidney damage (127, 128), diabetes (129-132),

diarrhoeal diseases (125, 133, 134), malaria (135), presentations to emergency departments (126, 136-138), heat stroke, organ failure (139, 140), and mental health problems (119, 141). Even more concerning, the concentration of atmospheric CO_2 expected by 2100 could directly damage mammalian brain and respiratory development prior to birth (142, 143).

Adverse perinatal outcomes worsen with climate change. The risk of preterm birth is already higher in low- and middle-income countries (120, 144) and is projected to increase (144). Globally, the risk increases with ambient temperature and heatwaves (4, 83, 122, 144, 145), and with lower socio-economic status (120). Preterm birth is a major contributor to infant mortality and lifelong health problems, including neurological impairment, chronic respiratory impairment, reduced growth, and other disorders (144, 146). Little is known about the pathophysiological mechanisms by which high temperatures increase preterm births, but a thermoregulatory problem in pregnant women exposed to extreme heat resulting in aberrant inflammatory responses has been proposed (147), and cortisol-induced uterine activity due to prostaglandin release has also been postulated (120, 148). More research to improve understanding of these mechanisms to develop strategies to mitigate the risk is required (147). In the meantime, resources are already scarce for maintaining children's health in low- and middle-income nations (1, 144), so a rapidly increasing population combined with climate change will *ipso facto* exacerbate preterm birth rates and further increase infant and child mortality (144).

Children's respiratory health is particularly vulnerable to population pressure and climate change (66, 67, 69, 106, 107). Globally, high temperatures increase the risk of respiratory disease in children (4). In Indonesia, Brazil, and India, high humidity increases the prevalence of childhood pneumonia (149). Pollutant exposure associated with climate change correlates with an increase in the prevalence of asthma, atopic dermatitis, and allergic rhinitis (150, 151). Air pollution is responsible for an estimated 236,000 deaths in the first month of life of newborns in Africa, and with 14% of all deaths in children under the age of 5 across that continent (67). Extreme temperature exposure and heat waves

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have also been associated with increased paediatric presentations to hospital for asthma in Australia (152), USA (119, 153), and South Africa (116). Child health will deteriorate as the climate changes, but this relationship is complex and influenced by many confounding factors, such as existing local climate conditions, infrastructure, and socioeconomic status (154, 155).

Climate change already strains systems that are essential for maintaining good child health, but particularly on those unable to cope with current numbers of children (1). Climate change also reduces food security (94), forces migration (156), and increases conflict (157). The latter leads to malnutrition, fewer educational opportunities for children, and more barriers to receiving health care (157). For every 1 °C increase in temperature, wheat production is expected to decline by 6% (158); 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 (159). 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.

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 (160, 161) and demonstrated a positive relationship between countries with the most children born and a higher child climate risk index (figure 3). This shows that, in general, countries where the climate risk is highest are those with the greatest numbers of children born.

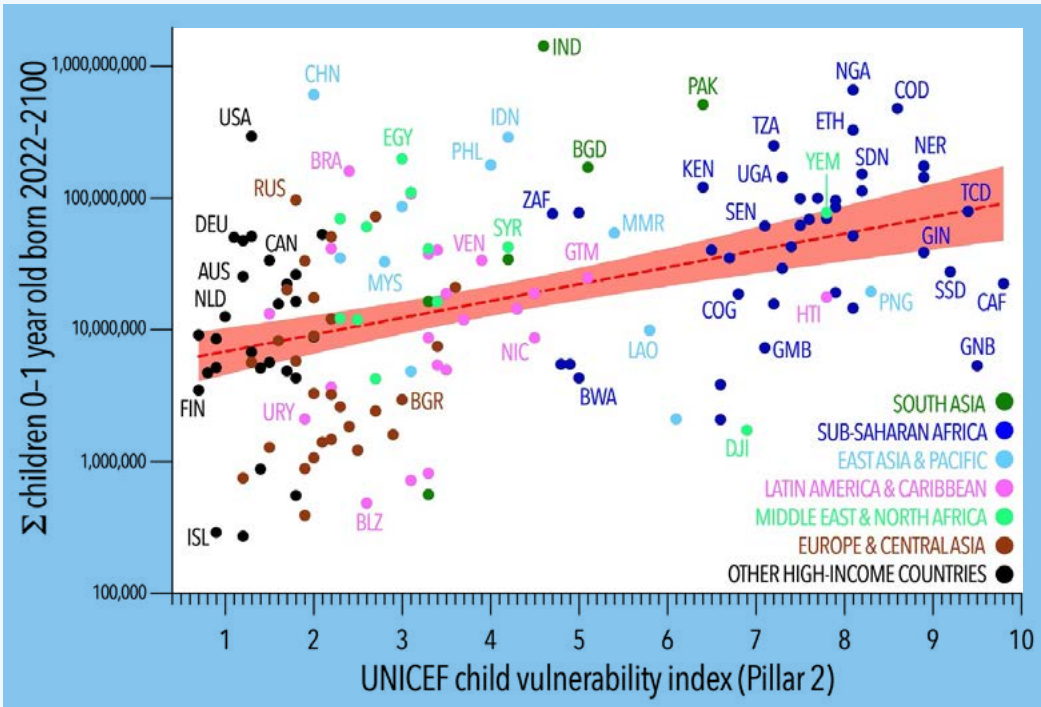

Figure 3. Number of children < 1 years old expected to be born and survive between 2022 and 2100 compared to the UNICEF child vulnerability score.

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 (162) predict 9.91 billion and 14.49 billion children, respectively will be born globally between 2023 and 2100 (Figure 4). For comparison, there were 134 million children born globally in 2021 (163), and there were 2.01 billion children aged 0–14 years in the world in 2022 (164).

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 (Figure 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 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 (165). 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).

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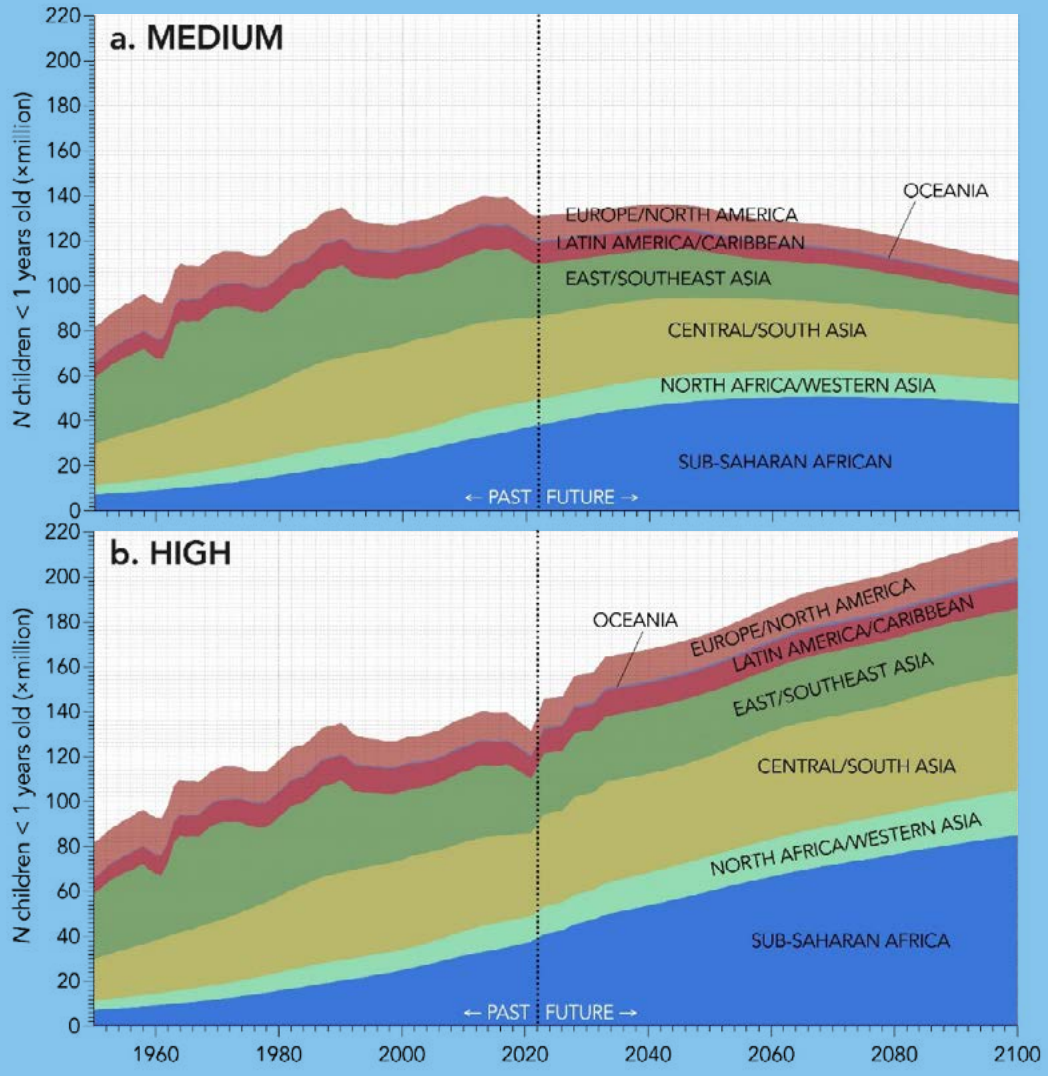


Figure 4. Annual numbers of children < 1 years old expected to be born between 2022 and 2100 for each world region for the United Nations' Medium (a) and *High* (b) growth models.

Interrelationships between population increase, poverty, and infant death

Poverty is a well-established predictor of infant and child mortality (166-169), 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 years 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.

As hypothesised, there is a strong relationship (R2 = 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).

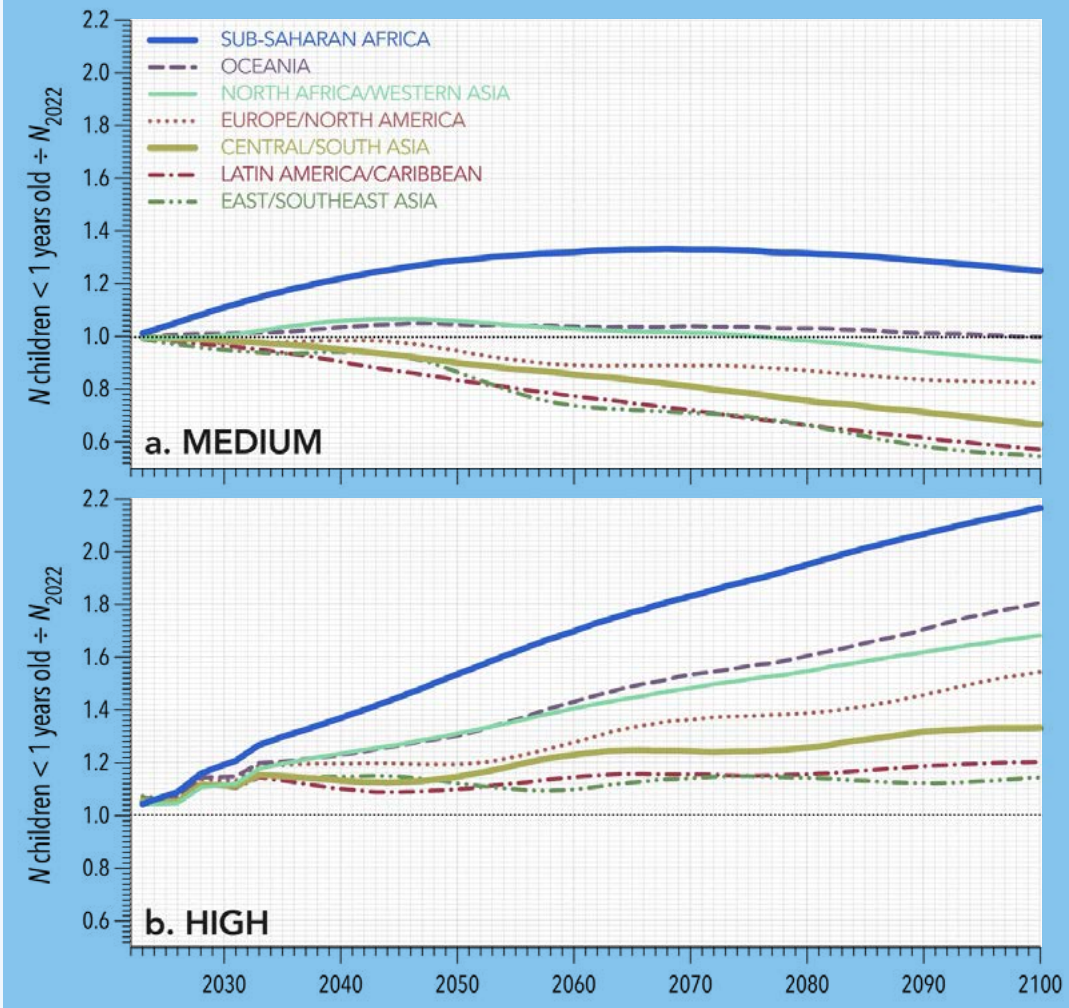


Figure 5. Projected annual ratio of children < 1 years old born to number of children < 1 years old born in 2022 for each world region based on the United Nations' *Medium* (a) and *High* (b) growth models. Horizontal black dotted line indicates a ratio = 1.

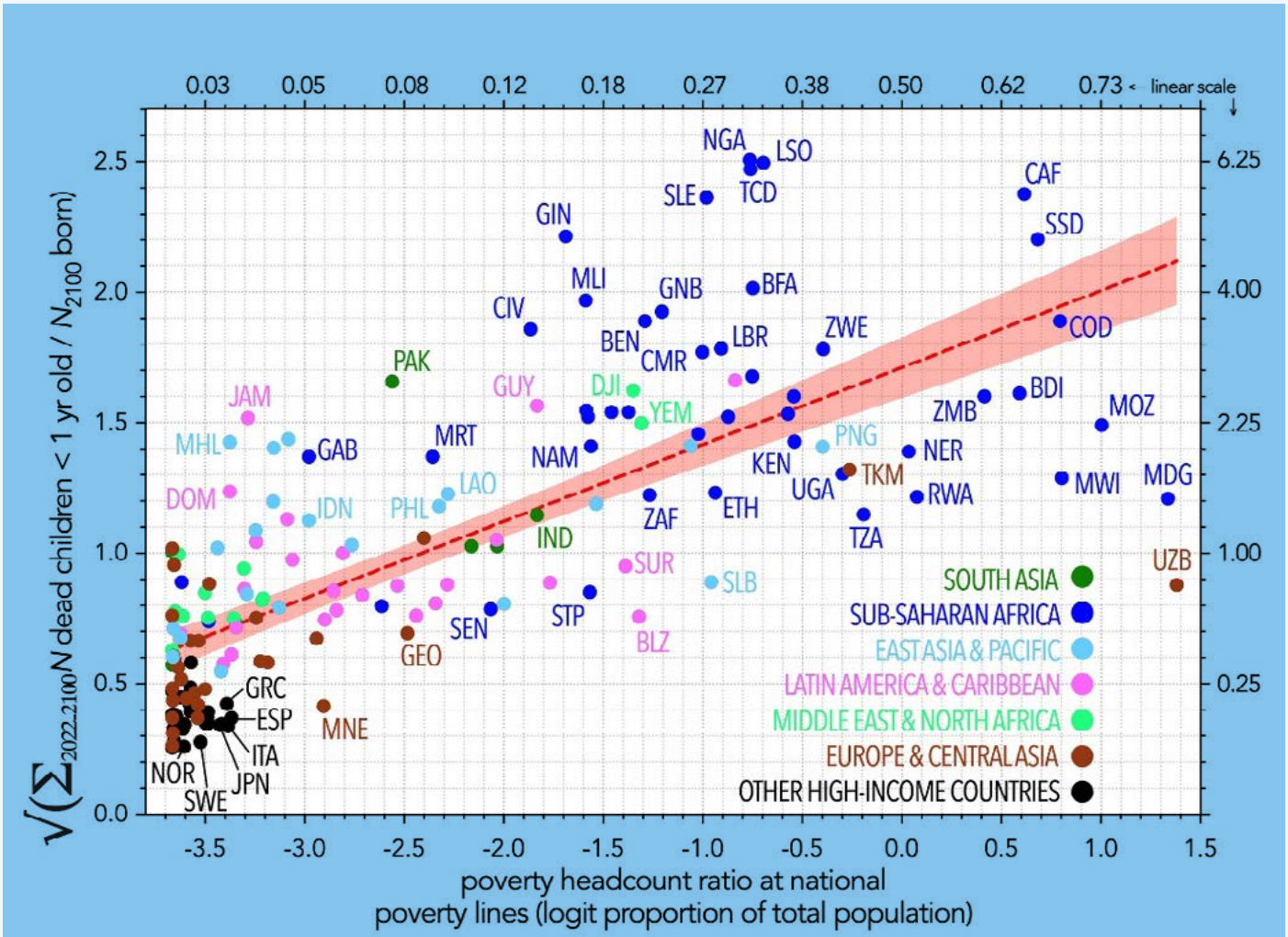


Figure 6. Relationship between population size-standardised child mortality (0–1 years old; square-root scale) and national-scale poverty (logit proportion of total population).

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

Averaging the residuals of the relationship shown in Figure 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 (Figure 8).

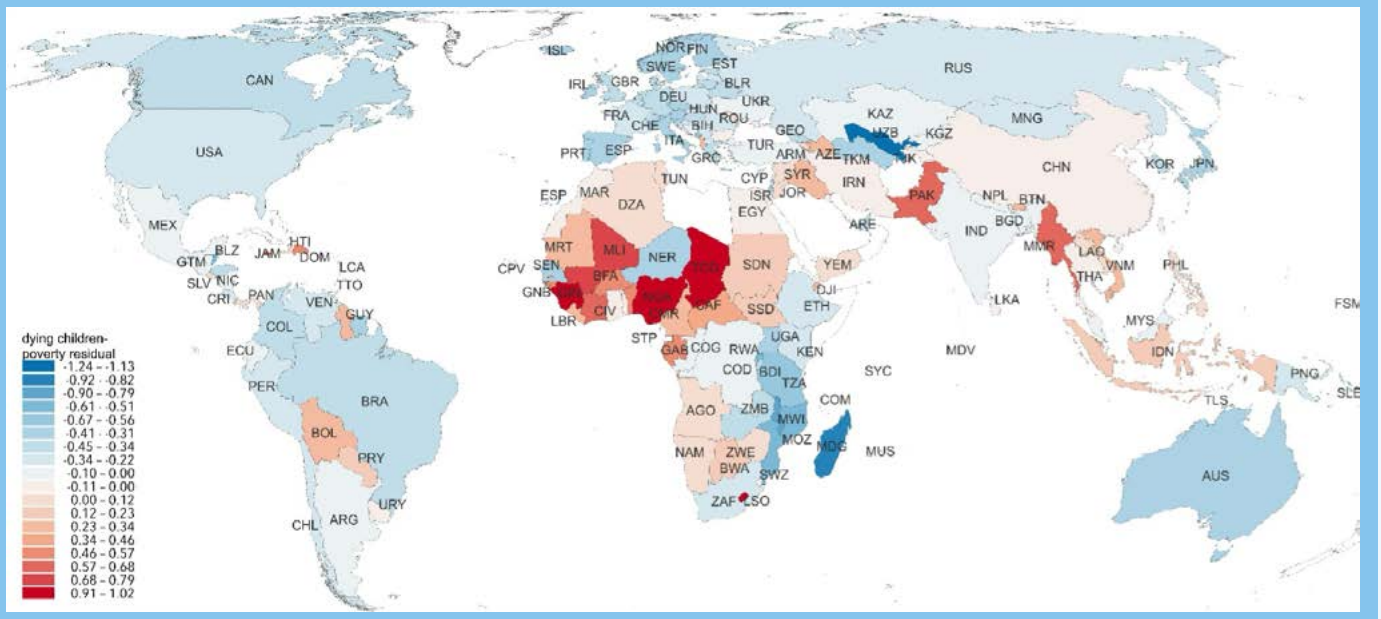


Figure 7. World map of the residuals from the relationship in Figure 5 – the redder the colour, the higher the poverty- and population-standardised child mortality; the bluer, the lower the poverty- and population-standardised child mortality (see residuals in Fig. 6).

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

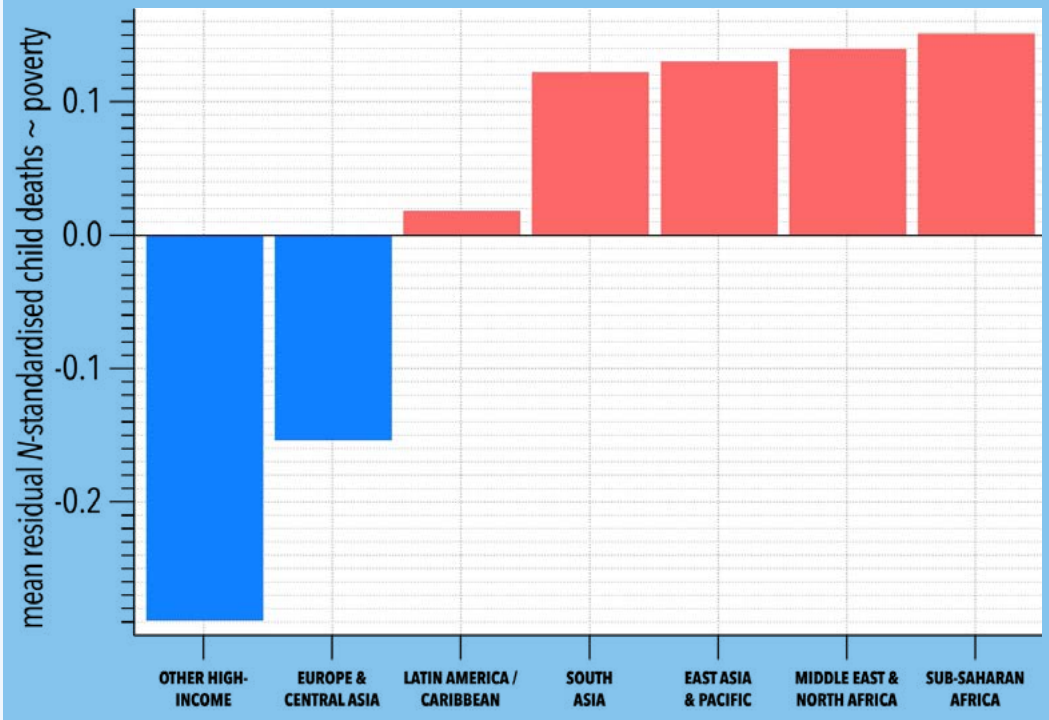


Figure 8. Mean residuals (across countries) of the relationship between population size-standardised child deaths predicted from 2022 to 2100 and national poverty (see Fig. 6) by major global region. Blue (mean negative residual) bars indicate the regions with lower-than-predicted child deaths, and red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

Assessing the effects of population pressure 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' methodology 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 (170), the time when improvements to health are reversed by climate change and population pressure might have already arrived, as recent evidence suggests that infant mortality is already increasing in countries from several different regions. For example, recent increases have been observed in both the United States and France (171, 172), as well as in India, Madagascar, Cambodia, Nepal, and the Philippines (173).

Access to quality family planning benefits children's health

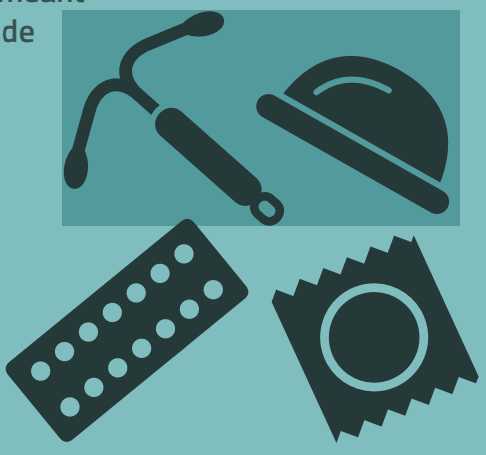
A proven approach to reducing fertility is to give all men and women access to free, voluntary, culturally sensitive, locally appropriate, quality family planning services. Such access allows prospective parents to choose the size of their family and is considered a human right (16). Even though this is part of the United Nations' Sustainable Development Goal 3.7 (174) and has been supported by the World Health Organization (16, 175), the unmet need has received less attention than climate change. According to a World Bank report, the intervention of meeting 90% of the unmet need for contraception alone in 2015 would have reduced annual global births by 28 million and averted 440,000 neonatal and 473,000 child deaths (176). Because countries with unmet contraception needs (177) are those with the highest fertility rates and the highest population growth (178), these numbers will increase over coming decades. With the likely decline in health as continuing rapid population growth in these countries outstrips resource availability, the true increase in neonatal and child deaths will be much greater. Reduced fertility will therefore help to protect future children from early death or a life of ill health.

Several factors beyond access to quality family planning are associated with lower fertility rates. These include higher maternal education (179), lower infant mortality (180), greater socio-economic prosperity (181), and lower religious adherence (182). Although these associations have often been interpreted as causal (179, 183), there are many potential confounding interactions. For example, women who are more educated are likely to be more prosperous than those who less-educated, and the relationship between high infant mortality and high fertility can be bi-directional in causality, because high infant mortality can increase fertility, whereas higher fertility can increase infant mortality (184-186). The evidence that fertility declines as soon as quality family planning is available is extensive, with poignant examples from Bangladesh (187-189), Kenya (190), and Iran (191, 192). At the country scale, lower fertility is related to lower infant mortality, lower household size, and increased access to contraception, each of these being more important than either female education or religious adherence (180).

There have been no modelled projections of the effects of various scenarios for increasing the availability of family planning in countries with unmet needs of contraception on infant mortality,

Family Planning for Women and Children's Health

Shortfalls in sexual and reproductive healthcare funding have meant an estimated 257 million women of child-bearing age worldwide still face an unmet need for family planning and safe, modern contraceptives. If urgent action is not taken, the number of women with unmet need for family planning will rise due to population growth outpacing the expansion of family planning services.



According to a World Bank report, the intervention of meeting 90% of the unmet need for contraception alone in 2015 would have reduced annual global births by 28 million and averted 440,000 neonatal and 473,000 child deaths (176).

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while simultaneously considering resource and nutrition limitation and climate change. Demonstrating the importance of this issue to the health of future children would provide compelling evidence for a much greater focus on implementing the introduction of high-quality family planning across the globe to reduce deaths and suffering in future generations of children.

Future prospects for children

We have provided the first summary of the evidence that population pressure is adversely affecting children and that further increases in population will have increasingly serious consequences for children in the future unless substantial measures are taken to reverse population growth. Our analyses emphasise that most children born this century will be in sub-Saharan Africa and Central/South Asia where malnutrition is already high, the capacity to increase crop yields is low, and the impacts of climate change on child health are high and already contributing to infant mortality. Low-income nations have the fewest resources to protect higher numbers of children from the effects of population pressure and the deteriorating climate. We also emphasise that the need to address population to protect future children must include wealthy, high-consumption nations. Achieving a sustainable global population size is 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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