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EDITORIAL

Population dynamics, economic growth and planetary boundaries

David Samways

While this journal is principally concerned with the population dimension of environmental sustainability, it is impossible to understand the role of demographic factors in environmental impact in isolation from their relationships to wider social and economic structures. At the broadest level of analysis, the IPAT equation is a useful heuristic device for capturing how population size (P), the per capita level of affluence or consumption (A), and the resource intensity of the technical means of production (T) affects environmental impact (I). Thus, the growth of the human enterprise in the industrial era can be crudely framed as the outcome of the use of fossil fuel technologies, the growth in human numbers and the growth in per capita material consumption. However, it is clear that the historical growth of human environmental impact has significantly outstripped population growth in comparison to the massive expansion of the global economy – in other words, consumption growth has been the greatest culprit (Steffen et al., 2015). Importantly, further disaggregation shows that the vast majority of the historical growth in consumption has been concentrated in the Global North (Steffen et al., 2015).

Yet despite this, while growing consumption remains the most significant factor, population growth continues to be a significant indirect driver of all impacts (Brondízio et al., 2019; Almond et al. 2022; IPCC, 2023). In respect of greenhouse gas emissions, economic growth accounted for around two thirds of their growth with population growth accounting for the rest. And while technical improvements and alternatives to fossil fuels have reduced the resource intensity of production, it has been shown that emissions due to population growth alone eclipsed more than 75 per cent of these savings (Chaurasia, 2020).

All forecasts predict the global population to grow well into the middle of this century (Lutz et al. 2018; Volsett et al. 2020; UN 2022). Viewed in the context of the multiple measures showing the transgression of sustainability (Steffen 2021; Lin et al 2018), this indicates that the prospects of providing good welfare for all within planetary boundaries to be dependent on significant global and regional changes in economic and social systems in addition to the necessary technical changes (O'Neill et al. 2018; Callegari and Stoknes 2023).

Despite the warnings of the scientific community, economic growth remains the global orthodoxy – a fact reflected in the centrality of economic growth in the manifestos of the major political parties in the recent UK general election, and common to political discourses in all rich, high consumption, countries. Nonetheless, with more than sixty per cent of the global population living on less than $10[1] a day and the majority of these people living in developing countries (Roser, 2021), it is clear that meeting their welfare needs will require their national economies to grow.

The United Nations Sustainable Development Goals (SDGs) aspire to square the need for economic development on a finite planet, but as Nandita Bajaj, Eileen Crist and Kirsten Stade argue in this issue, the UN fails to fully acknowledge the full extent of the environmental crisis wrought by the present and growing size of the human enterprise. Bajaj, Crist and Stade contend that, as a pivotal agent of post-war international governance and development, the project of the United Nations was and continues to be framed in a growth paradigm. Summarising the ecological overshoot[2] consequent on the massive expansion of the human enterprise, Bajaj et al. identify growth in population, the economy and the technosphere as the major factors in the environmental crisis. All three factors can be understood as having a quantitative or population dimension in terms of the growth in the population of economic consumers[3] and populations of all associated human 'stuff' including livestock, infrastructure, buildings, mechanical and electronic devices etc. Bajaj and colleagues argue that, at its founding, the UN reflected the prevailing notions of human exceptionalism which saw nature merely as a resource employed in the pursuit of endless economic growth and

1 International-$ at 2011 prices.

2 The exceeding of the capacity of natural systems to absorb and process the waste generated by human activity.

3 Economic consumption here understood as qualitatively distinct from simple economic subsistence.

prosperity. What boundaries were considered to exist could be overcome through human intelligence and technology.

However, as Bajaj et al. relate, the UN's position on human population growth did not entirely concur with this exceptionalist ideology. Prior to the 1970s, the UN embraced concern about population growth being a fetter to development and possibly outpacing food production (Bongaarts and Hodgson, 2022) and pursued active rights-based policies which had a significant impact on lowering fertility. Yet, by the 1990s, the UN, under the influence of a somewhat unlikely sounding coalition of stakeholders including feminists, human rights advocates, religious conservatives and neoliberal economists, radically shifted its position, sidelining the concerns of demographers, family planning advocates and environmentalists. According to Bajaj et al. the UN's 1994 Cairo population conference 'became the death knell for an understanding that a sustainable population and the elevation of human rights could be *twin goals* for achieving reproductive and ecological justice'. International funding for family planning plummeted and regressive pronatalism thrived resulting in the stalling or reversal of fertility declines in countries experiencing high population growth.

Despite the clear evidence of environmental overshoot and of economic and population growth as indirect drivers, Bajaj et al argue that the United Nations remains resolutely wedded to a growthist agenda and largely denies the connection between population growth and environmental harm. Interrogating the United Nations Population Fund's (UNFPA) 2023 State of the World Population report, Bajaj et al. find insufficient attention paid to pronatalist pressures combined with attempts to repudiate respected scientific work (such as that from the UN sponsored IPCC) which connects population growth with the environmental crisis. Indeed, the authors find that the UN in general is in a state of denial regarding population growth and pins its hopes on so called 'green economic growth' to achieve its developmental and security objectives.

Bajaj, Crist and Stade conclude that, in order to address the environmental crisis, the UN must break with its current ideological paradigm and lead the way in reducing the size and scale of the human enterprise. This can be achieved principally through rights-based population reduction and scaling back the global economy by focussing on welfare rather than economic growth. In turn this will help reduce the size of the technosphere, allowing ecosystems and other species to revive.

The question of sustainable economic development is considered at a more granular level in our next article by Akosua Mawuse Amankwah, Edward Appiah, Charles Frimpong and Aguinaldo dos Santos. The UN's SDG 12 calls for reductions in production and consumption and Amankwah et al. note that circular economic strategies, following principles of reduce, reuse and recycle, could be employed to achieve this goal in the developing Ghanaian fashion industry whilst also meeting the needs of a growing and more affluent population.

Ghana's population currently stands at around thirty million and is expected to grow significantly this century. Importantly, like most developing countries, Ghana is rapidly urbanising with nearly half of all urbanisation over the last decade occurring in the two major economic regions of Greater Accra and Ashanti. Ghana's population structure has also shifted as the dominance of children under the age of fourteen has given way to a youth-bulge of 14–35 year-olds. Along with these quantitative demographic shifts, the authors point to the growth of the urban middle-class as contributing to a boom in Ghana's fashion industry. However, the clothing industry is associated with a number of environmental problems at both ends of a garment's life-cycle.

In this context Amankwah and colleagues investigate the potential for the up-take of circular economic strategies amongst owner-designers of small and medium-sized clothing manufacturers. They find that, although some businesses are already and unknowingly employing circular economic strategies, producers are understandably focused on the economics of their enterprises rather than environmental sustainability and other factors. Owners cite cost, time, labour as well as consumer attitude and behaviour as barriers to shifting to circular strategies. However, Amankwah et al. argue that, with the right government policies aimed at creating awareness and encouraging adoption and implementation, circular strategies could be effective in making the clothing industry in Ghana more sustainable in the face of increasing demand.

As Baja et al. note in their survey of ecological overshoot, one of the major challenges facing a growing population is that of freshwater availability. Unlike many other resources essential to our civilisation, water is entirely renewable – in practical terms the amount of water on the planet does not change. It is the spatial and temporal availability along with changes in the quality of water that is at the core of the water problem. In the scientific literature, along with changing consumption (usually associated with changing practices linked to increasing affluence), population growth is universally recognised as a major factor in the anthropogenic disruption of the water cycle and a challenge going forward. However, it is also the case that over the last century demand for water has grown twice as fast as population (Liu et al., 2022). This disruption is further exacerbated by climate change leading to shifting weather patterns depleting precipitation in some areas/seasons and increasing it in others. Since water is a renewable resource, unsustainable use comes down to the depletion of stocks at a faster rate than they are replenished by flows.

Our *Perspective* article from John Pattison and Peter Cooke looks at the problem of 'global drying', as population growth, urbanisation and climate change lead to stress on groundwater aquifers – which account for thirty per cent of freshwater resources. As the authors note, discussion of global warming and sea level rise is common, but the depletion of groundwater aquifers less so. Through a range of examples, Pattinson and Cooke focus on the most striking visible effect of groundwater depletion – sinking cities. While sea levels are rising and threatening island nations, many cities such as Mexico City are experiencing serious building subsidence as the ancient aquifers on which they are built are depleted leading to unstable ground conditions. They point out that, while increasing affluence is a major driver of the growth in demand for freshwater, both population growth per se, but more particularly urbanisation, have exacerbated total urban water consumption and led to many cities and regions to abstract water from ancient aquifers at a faster rate than it can be replenished. Importantly, until subsidence occurs, aquifer depletion is invisible, which encourages mismanagement from organisations often focussed on short-term political objectives. Moreover, private abstraction via bore-holes or wells is difficult to regulate. Pattison and Cooke ask 'can a good life be provided to all within regional water boundaries if they are better managed?' Forward planning in the management and governance of water resources is clearly a central consideration in sustainability, but Pattison and Cooke draw attention to tackling population growth as part of the long-term strategy of providing sufficient fresh water to all.

In our final article, Aalok Chaurasia analyses the detail of the mortality transitions of China and India. He points out that as the world's most populous countries, constituting around 36 per cent of the total global population (UN, 2022), the demographic prospects of China and India are closely linked to future global demographic trends. Presently both have similar population sizes – just over 1.4 billion. However, China and India show significant differences in their mortality transition over the last seven decades. In 1950, both were developmentally and demographically similar but, where China is at an advanced stage of demographic transition with its population just starting to decline, India's population is still growing. Moreover, over the same period, life expectancy at birth has gone from the early 40s in both countries to more than 78 years in China but only a little over 67 years in India.

Nonetheless, Chaurasia shows that the conventional measure of aggregate average life expectancy at birth is compromised and obscures much detail. He argues that for the analysis of the aggregate mortality transition the geometric mean of the age-specific probabilities of death is more representative of the actual population. More importantly, at the more granular level, employing a time trend and decomposition analysis to compare the mortality transition in the two countries, Chaurasia shows that China's mortality transition has been fairly evenly spread across all age cohorts, meaning that both child mortality and mortality for other age groups has improved. In contrast, India's mortality transition has largely been confined to younger age groups with little mortality transition occurring in the 55–90 age group.

Since India's total fertility rate is now at replacement levels and likely to continue to fall, in years to come population ageing will be a more significant issue. Chaurasia argues that India's healthcare system must be reinvigorated and shift from the successful delivery of healthcare tackling infectious and communicable diseases amongst the young, towards the particular healthcare needs of its growing older population.

Ageing populations are not confined to India and China, of course; the population is ageing globally. Under all projection scenarios, while the global population will continue to grow in this century, the global average total fertility rate is expected to continue falling, shifting the population age structure upwards (Lutz et al. 2018;

Volsett et al. 2020; UN, 2022). By 2050 over-65s will constitute sixteen per cent of the population and will outnumber children under five by 2:1 (UN, 2022).

The fact that, since 1950, the global average length of life, or life expectancy at birth, has increased from 46 to more than 78 years (Andreev et al., 2013; United Nations, 2022) might suggest that the claim 'most of our population growth is not due to births but to most of us living much longer' (Dorling, 2022) is correct. However, most of the increase in life expectancy is not due to years added at the end of life but due to declines in infant and adolescent mortality. Prior to the industrial era, across all types of society, it is thought that around half of all children died before reaching puberty but, over the last 200 years, infant and child mortality has fallen to the current level of just over four per cent (Dattani et al., 2023). This child mortality transition has been the principal driver of population growth since survival into adulthood has a multiplier effect on population as people go on to have children of their own, while longevity after family building does not. Increasing longevity does contribute to population growth, but its major effect is to retard the point at which births fall below deaths. At present births exceed deaths by about seventy million a year and, although this figure is expected to decrease, births are expected to continue to exceed deaths until 2085 (UN, 2022). Even when the reductions in mortality across all ages are aggregated into a single figure, fertility and population momentum combined, that is births, will contribute the greatest amount to population growth over the next century (Andreev et al., 2013).

Across the world, but more immediately in high income countries, population ageing represents a significant adaptive challenge (Volsett et al. 2020). Policymakers in many nations with below replacement birth rates, such as Japan, South Korea, much of Europe, the United States and more recently China, have expressed concern about the economic and social consequences (as well as the geopolitical implications) of population ageing and the shrinking of the working age population (Economist, 2024). In some countries the response has been the enactment of pronatalist policies, but these have proved impotent in increasing the birth rate (Economist, 2024). Immigration has also been posited as the solution to labour shortages – however recent experience across Europe and America indicates this would not be achieved without political difficulty. The extent to which the alarmism around population ageing is justified is debatable (see Spijker and MacInnes 2013; Calvo-Sotomayor et al., 2020), yet clearly regional population shrinking is highly problematic to the growthist paradigm which dominates economic and political discourses. Bajaj, Crist and Stade's critique of the orthodoxy that claims economic growth as the route to a good life for all appears apposite to tackling the social as well as the environmental problems facing late modernity.

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PEER REVIEWED ARTICLE

Confronting the United Nations' pro-growth agenda: A call to reverse ecological overshoot

Nandita Bajaj,[1] Eileen Crist[2] and Kirsten Stade[3]

Abstract

In this article, we enjoin the United Nations (UN) to forge a path out of our plight of multiple environmental and social crises. With other analysts, we identify 'overshoot' – the state in which humanity has substantially outpaced Earth's capacity to regenerate its natural systems and to absorb our waste output – as the root cause of the existential threats we face. This dangerous condition demands rethinking our relationship with Earth and embarking on scaling down the human enterprise within policy frameworks of equity and rights. We argue that when the UN first articulated its international unity and prosperity mission, it did so within a 'growth' paradigm that treats Earth and its nonhuman inhabitants as mere resources at humanity's disposal. The 1994 Cairo Conference on Population and Development reinforced this agenda, with its sharp turn away from the earlier emphasis on population concerns and their link to environmental protection. Today, it is clear that the UN's foundational goals of peace, human rights and sustainability flounder within a growth-driven framework of human exceptionalism and nature domination. To correct course and reverse our advanced state of ecological overshoot,

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we urge the UN to lead in contracting the large-scale variables of the human enterprise – population, economy, technosphere – and to resist co-optation by political, ideological and special interest pressures that would derail this mandate.

Keywords: ecological overshoot, human exceptionalism, pronatalism, degrowth, United Nations, human rights, ecological justice

Introduction

The United Nations (UN) was created in 1945 with the historic pledge to uphold world peace and serve as an institutional setting for collaboration among all nations. Eighty years later, we find ourselves in the midst of multiple social and ecological crises. These dire and mounting threats stem from our advanced condition of overshoot, which describes our predicament wherein the growth of the global economy has substantially outpaced the capacity of Earth's natural systems – marine, forest, grasslands, wetlands, freshwater, soils – to process human waste output and regenerate their ecological wealth and biodiversity (Rees, 2023).

The UN emerged from prevailing ideas at the time of its founding, including that endless economic growth brings prosperity and wellbeing, that human ingenuity can overcome all constraints to growth, and that nature and nonhumans exist as 'resources' to serve us (Kuhlemann, 2020). While these ideas have directly led to the present-day cascading crises, the UN appears invested in their obsolete framing even as circumstances are becoming more desperate.

Since the mid-twentieth century, the expansion of the human enterprise has accelerated on a number of interconnected levels: growth of economic extraction, production and trade; increased consumption and higher standards of living (for some); increasing energy use; a growing global consumer population; enormous growth of the food sector; relentless technological (including infrastructural) sprawl; and exponential increase of the human population and the global livestock population (Steffen et al., 2015; Rees, 2023). (The combined latter populations now comprise 96 per cent of mammalian biomass [Bar-On et al., 2018]). Meanwhile, a 2020 *Science* publication offered a sobering quantification of technospheric growth (Stokstad, 2020). While 120 years ago the mass of the technosphere (the total amount of man-made stuff) was three per cent of Earth's biomass, by 2020 the technosphere exceeded the weight of all living beings. By 2040, the mass of human stuff is projected to grow to three times the planet's biomass. Briefly put, the industrial technosphere, serving eight billion people connected within a global capitalist system, is overtaking the planet.

What we have learned is that this explosion of growth, at breakneck speed, is a recipe for climate breakdown, mass extinction and global toxification, destabilising all complex life and undermining humanity's prospects for high-quality living and even for survival (Ripple et al., 2017; DellaSala et al., 2018; Díaz et al., 2019; Ceballos et al., 2020; Bradshaw et al., 2021; Rees, 2023).

In this article, we argue that the UN needs to reassess its growth-biased orientation and extricate itself from the corporate and religious interests that are undermining its professed goals of peace, prosperity and stability. We include a brief review of the UN's history, including its departure, under the influence of these interests, from acknowledging and addressing the ecological harms of unmitigated demographic and economic growth. We outline a path toward correcting our advanced state of ecological overshoot, beginning with resurrecting leadership on reducing the global population through rights-based approaches. In addition, we urge the UN to acknowledge and part ways with its human-exceptionalist approaches that treat nature and nonhuman beings as resources for human exploitation, approaches that have ripped the fabric of Earth's life-sustaining biophysical systems. In addition to offering counsel on population reduction strategies, we present current literature on pathways to contracting our economic excesses with attention to equity and justice.

Confronting ecological overshoot

If the nineteenth and twentieth centuries were the centuries of 'progress', wherein material prosperity and technological advancement appeared within reach of all humanity, the twenty-first century and beyond are the time of reckoning with the ignored externalities and consequences of this progress. Overshoot is the engine of an anthropogenic mass extinction event that recent scientific reports warn is accelerating (Steffen et al., 2015; Díaz et al., 2019; Ceballos et al., 2020; Rees, 2023). Overshoot also undermines nature's capacity to mitigate climate change on a double register: human-driven global heating releases carbon stored in Earth's ecosystems and soils, while continued destructive incursions into ecosystems weaken their capacity to absorb emissions (Steffen et al., 2018).

Alongside the perils of ecological drawdown and rapid climate change, overshoot of industrial humanity is also driving environmental contamination from local to global scales. Earth's biosphere may be likened to a thin film of life encompassing the planet and extending a few kilometres into crust and atmosphere. This finite envelope, within which all life exists in a relatively closed system, is increasingly besieged by toxic substances like plastics, fertilisers, pesticides, herbicides, heavy metals, industrial chemicals and pharmaceutical waste (DellaSala et al., 2018). The mounting pollution and degradation of the biosphere are attenuating the epidemiological environment of life, promoting conditions for infectious, zoonotic and chronic disease to spread (Ehrlich and Ehrlich, 2013).

A further dangerous outgrowth of overshoot is its potential to fuel conflict. Overshoot induces growing scarcities, dislocation of populations, disruption of supply chains, adverse harvest events and freshwater depletion and pollution (Klare, 2014; Bradshaw et al., 2021).

In brief, overshoot is the underlying driver of climate breakdown, biodiversity collapse, global toxification and aggravation of social conflicts and war. This predicament lowers the quality of life of present and future people, has a corrosive influence on democratic institutions, presents opportunity for dangerous demagogues and tyrants and reduces the capacity of young people to believe in a bright future. The accelerating condition of overshoot – the outcome of too many people having (or desiring) a high consumption standard of living, in a polluted world of declining 'resources' – tends to foster divisive and fear-driven socio-psychological states. Overshoot makes humanity far less conducive to the noble inclinations of human nature, like sharing, collaborating and equitably coexisting (Rieder, 2024).

It is clear that we must act as an international community, with meaningful contributions from UN leadership, to confront the root cause of our plight while there is still time to be proactive. The called-for programme of action is audacious in scope but simple to articulate: there must be fewer of us, extracting, producing and consuming less, and living far more equitably within the entire community of life (Jackson and Jensen, 2022; Fletcher, et al., 2024). At our stage of advanced overshoot, this programme of action is mandatory simply for survival and prevention of unnecessary death and suffering. Importantly, it also lays the groundwork for a world underpinned by a planetary reality where biodiversity and its ecological gifts are restored to their abundances, complexity and resilience, and there are enough sources of livelihood for all to enjoy a simple but high-quality standard of living.

In sum, countermanding overshoot with the goal of fewer of us, consuming less, with a commitment to equity, is about more than survival. It promises a redirection of human history away from the modalities of conquest, colonisation, exploitation, killing, conflict, war between humans and what UN Secretary General Antonio Guterres has called 'our suicidal war on nature' (UN, 2021b).

The UN's early population efforts

Earlier in the UN's history, the institution embraced the necessity of addressing population and played a pivotal role in focusing international attention in rights-based efforts to lower fertility. In the years following the UN's creation, demographic studies elucidated the realities of unprecedented population growth that were undermining efforts at peacekeeping and instituting human rights. In collaboration with the International Union for the Scientific Study of Population (IUSSP), the UN convened its first world population conferences in 1954 (Rome) and 1965 (Belgrade) to discuss solutions to challenges related to population growth. What followed was an extraordinary period of international investment in rights-based programmes, including education for women and girls and publicly funded family planning programmes. These approaches brought tremendous gains in lowered fertility, reduced poverty and enhanced autonomy for women and girls (DeJong, 2000; Weisman, 2013; de Silva and Tenreyro, 2017; Kuhlemann, 2020; Bongaarts and Hodgson, 2022).

The UN's 1994 Cairo conference: population concerns abandoned

Yet in the population conferences held in the decades that followed, namely 1974 (Bucharest) and 1984 (Mexico City), this spirit of frankly acknowledging and addressing population challenges began to shift (DeJong, 2000; Coole, 2021). By the 1990s, the subject had become so contentious that the 1994 International Conference on Population and Development in Cairo, Egypt culminated with an abrupt departure from acknowledging the role of population deceleration in promoting ecological sustainability and human rights. Feminist and social justice advocates, religious conservatives, and trade and economic interests united to delegitimise population concerns brought forth by demographers, family planning advocates and environmentalists at the Cairo conference (DeJong, 2000; Campbell and Bedford, 2009; Weisman, 2013; Kuhlemann, 2020; Coole, 2021; Bongaarts and Hodgson, 2022). A key factor in this ideological turn was the ascension of the New Right in the United States, as the Reagan Administration conjoined neoliberal economics and social-religious conservatism. Buttressed by the conviction that human population increase was necessary for economic growth, the powerful proponents of this emerging ideology rejected state-level protectionist and welfare support, including for family planning initiatives that they branded 'neo-Malthusian'. In their formulation, opening markets for trade would itself lower fertility as it propelled development, with no need for direct investment in family planning (DeJong, 2000; Coole, 2021). Professed concern for the vulnerable notwithstanding, the motive for shifting toward a free trade emphasis was the drive by elites in both the developing and developed world to exploit developing nations' cheap resources (Shrivastava and Kothari, 2012; Coole, 2021).

The presence of the Vatican and other conservative religious interests at Cairo, and their vociferous opposition to birth control and abortion, cemented the shift away from voluntary family planning policies and female empowerment as pathways to reduced fertility rates, higher quality of life and nature protection (DeJong, 2000; Coole, 2021; Bongaarts and Hodgson, 2022). Ultimately, due to the presence of a constellation of interests that were for their own reasons hostile to family planning, the Cairo conference became the death knell for an understanding that a sustainable population and the elevation of human rights could be *twin goals* for achieving reproductive and ecological justice. Feminists, concerned by instances of 'population control' efforts that had included coercive measures, joined trade and religious advocates in upholding this newfangled population denialism, despite the fact that the vast majority of family planning initiatives over preceding decades were *voluntary* and indisputably elevated women's reproductive rights and improved the quality of human life (Robinson and Ross, 2007; Weisman, 2013; de Silva and Tenreyro, 2017; Coole, 2021; Bongaarts and Hodgson, 2022).

The aftermath of the UN's 1994 Cairo conference

The consequences have been devastating. In the decades since the 1994 Cairo conference, international funding for family planning plummeted by 35 per cent, and it continues to fall far short of the global unmet need for contraception (Sinding, 2008; Grollman et al., 2018). The result has been the stalling, or even reversal, of fertility declines in many countries experiencing rapid population growth (Bongaarts and Hodgson, 2022).

What the reproductive-rights community, including many feminists, missed in this historical moment was the enormous sway of pronatalism, a coercive population-growth factor far more prevalent than any 'population control' measures employed to lower fertility (Campbell and Bedford, 2009; Kuhlemann, 2020; Coole, 2021; Bajaj and Stade, 2023). Pronatalism is a constellation of patriarchal, religious, nationalistic and economic pressures on women to bear children, precisely in order to strengthen those power structures. Pronatalism emerged as institutionalised patriarchy came to prevail with the rise some 5,000 years ago of early states and empires that depended on population expansion and seizure of resources to consolidate power (Saini, 2023). It remains enormously pervasive and oppressive in the lives of girls and women and continues to be the steadfast engine of population growth.

With the ideological turn away from population concerns instigated three decades ago, pronatalism has been allowed to thrive in the obfuscation spawned by a superficial view of human and reproductive rights. The emergent discourse about family planning privileged the ostensible 'right of parents' to procreate, overlooking both the sociocultural coercive pressures on girls and women to bear children and the rights of children to be born into social and ecological conditions that are conducive to their wellbeing (Hedberg, 2020; Kuhlemann, 2020; Rieder, 2024). Additionally, the abandonment of the population factor meant that its undeniable relevance to safeguarding the natural world and future generations went missing from the public domain and international policy (Kuhlemann, 2020; Coole, 2021).

UNFPA population denial today: 2023 State of World Population Report

To this day, the ties of population size and growth to ecological and human wellbeing remain a largely proscribed subject within the UN, as reflected in the 2023 State of World Population (SWOP) report by the United Nations Population

Fund (UNFPA). The SWOP report demonstrates how the agency's extreme reluctance to address the population factor has resulted in messaging that excludes the impact of demographic realities on women, girls, ecosystems and vulnerable human communities. Its glib title, '8 Billion Lives, Infinite Possibilities', suggests a strong disinclination for a nuanced discussion of the challenges posed by population growth (UNFPA, 2023).

The report dismisses numerous studies by reputable scientists that draw conclusive links between growth in human numbers and climate breakdown, biodiversity loss, species extinctions, resource scarcity, conflict, poverty, food insecurity and more, labelling those studies 'modern Malthusianism' – a term popularised by the pro-growth and religious right movement of the 1980s (DeJong, 2000; Coole, 2021). Instead of conceding the obvious role of human numbers in these compounding crises, and the environmental and social benefits that would accrue from fewer people, the report vaguely alludes to 'reducing emissions' and 'increasing sustainable production and consumption' as strategies to address climate change, while leaving virtually unacknowledged that climate change is but one existential threat out of many in our state of overshoot.

The report goes so far as to deny outright the relevance of population size, citing a statement from the Union of Concerned Scientists that, 'A misplaced focus on population growth as a key driver of… climate change conflates a rise in emissions with an increase in people, rather than… an increase in cars, power plants, airplanes, industries, buildings' (UCS, 2022 as cited in UNFPA, 2023). The implication here is that the technology and infrastructures that produce climate-wrecking emissions are wielded solely by a consumer minority residing in wealthy, low-fertility countries. This view entirely discounts the global reality of a rising middle class that is responsible for all that technology and infrastructures – a global consumer class that is projected to reach five billion within this decade alone (Kharas, 2017). The report's view appears to assume that the billions of people living in poverty today will not seek to improve their standard of living and thus increase their share in 'cars, power plants, airplanes, industries, buildings' (see Rees, 2023). Meanwhile, the ignored science behind the UN-sponsored IPCC report conclusively shows that, 'Globally, GDP per capita *and* population growth remained the strongest drivers of CO2 emissions from fossil fuel combustion in the last decade' (IPCC, 2022a, emphasis added).

SWOP 2023 ignores pronatalist pressures

UNFPA's refusal to consider the population factor is based on its contention that to do so places responsibility for the climate and other global crises on women and girls, thus 'weaponizing … women's rights to contraception and education'. What the report elides, however, is that these very rights are violated by pronatalist pressures worldwide: women and girls regularly face domestic violence, sexual abuse, divorce, economic marginalisation and social ostracism as a result of their inability or refusal to have the number of children dictated by high-fertility societal norms (Dasgupta and Dasgupta, 2017; Ikeke, 2021; Ullah et al., 2021; Bajaj, 2023; Pirnia et al., 2023).

Pronatalist pressures are only worsening, with numerous countries spreading alarmist rhetoric about 'human population collapse' to justify policies ranging from baby bonuses and legally reduced marital age, to restricting abortion and contraception, and even subsidising the multi-billion dollar assisted reproductive technologies industry (Bajaj and Stade, 2023; Fassbender et al., 2023). As admitted in the report, these pronatalist policies and narratives often include ethnocentric, anti-immigration and nationalist rhetoric that advance elitist, political and economic agendas as well as religious and racist ones (UN DESA, 2021; UNFPA, 2023). These rising pronatalist trends constitute an enormous regression of hard-won human rights. Taking concrete steps to oppose them should be a priority for the UN and other bodies concerned with strengthening reproductive rights. Yet UNFPA gives only passing attention to these emergent trends, prioritising their insistence that population size and growth bear no relevance to nature protection or human rights and wellbeing (Bajaj, 2023).

Ironically, realistic acknowledgment of how demographic trends fuel major social and ecological challenges would in no way interfere with the UNFPA's stated priority of strengthening female rights and autonomy. Across the world, in country after country, once women achieve the education, empowerment and means to plan their families, fertility declines. This trend is so strikingly uniform across religious, cultural and political contexts that it has revealed women's 'latent desire' for lower fertility – a general preference that surfaces forthrightly once conditions for women's authentic choices align (Robinson and Ross, 2007; Campbell and Bedford, 2009; Weisman, 2013; Engelman, 2016; Bongaarts and Hodgson, 2022; Speidel and O'Sullivan, 2023). Providing the means for women to control their fertility, while also providing science-based information about how procreation relates to climate, biodiversity, clean water and other environmental concerns, will support women to realise their latent desire for fewer, well-cared-for children and also support their decision, if they so choose, to remain childfree. Such a shift toward female empowerment would correct for millennia of patriarchal pronatalism that has pressured women to be breeding machines.

The assumption that women should be spared accurate information about population impacts – lest they plan their families based on a comprehensive picture of the consequences not only for themselves but for present and future societies, for children and for the planet – is condescending (Hedberg, 2020; Rieder, 2024). The report repeatedly invokes the 1994 Cairo Conference Programme of Action, which lists as a core principle that all people have 'the basic right to decide freely and responsibly the number and spacing of their children and to have the information, education and means to do so' (UN, 1994). Yet a comprehensive picture regarding the impacts of reproductive decisions on the prospective parents themselves, as well as on the children, society and planet, is *precisely* what would enable reproductive decisions to be 'free and responsible'. The SWOP report assumes that only would-be parents have 'rights', that they make decisions in a sociocultural and ecological vacuum, that the coercion of girls and women to procreate is irrelevant, and that ecological impacts of reproductive decision-making at local and global scales are discountable.

Refusal to admit the enormous implications of population size and growth suggests that the UNFPA espouses the pronatalist forces it turns a blind eye to (Bajaj, 2023). Despite passing mention of the influence of pronatalist pressures, the report assumes motherhood to be women's desired 'natural' path, and reinforces this assumption with examples of remorseful women foregoing motherhood because of the climate crisis, or through selected studies highlighting involuntary childlessness due to infertility or other circumstances.

We agree that experiences of missed motherhood, and a sense of grief that may accompany them, need to be acknowledged. Absent from the report, however, is appreciation of the extent to which such experiences are shaped by oppressive forces, which stigmatise those facing infertility and insist on biological motherhood as the expected, default path (Greil et al., 2011; Ullah et al., 2021; Pirnia et al., 2023). The report even casts a favourable light on state subsidisation of the fertility industry, while sweeping under the rug the ways in which this industry exploits socially constructed fears of childlessness, causes psychological and physical harms through aggressive interventions, and further entrenches biological-motherhood-is-destiny notions of womanhood (Tsigdinos, 2021; Turkmendag, 2022; Fassbender et al., 2023).

While extensively canvassing historic examples of forced sterilisation to control populations, the report makes no mention of the well-documented difficulties women face in obtaining voluntary sterilisation due to pronatalist medical institutions and state policies (Lalonde, 2018; Hintz and Brown, 2019). Instead of choosing to promote the predatory fertility industry, the report might have included discussion of people leading fulfilling lives as single and childfree adults, as well as within adoptive families or families created with nonhuman kin. Given the extent to which such choices are stigmatised within most cultures, normalising diverse family choices and hitherto nonconventional alternatives makes ethical and prudential sense (Neal and Neal, 2022; Bajaj and Stade, 2023). The report also missed a precious opportunity to elevate parenthood through adoption, which is a mindful choice for creating or enlarging families, especially given that millions of children worldwide are estimated to live in settings vulnerable to violence, abuse, neglect and exploitation, and are in need of loving homes (UNICEF, 2017; Hedberg, 2020; Rieder, 2024).

SWOP 2023 ignores the rights of children

Indeed, the most glaring oversight of a report devoted to reproduction matters was the omission of any mention, let alone discussion, of *the rights of children* to be born into conditions that support their material, psychological and spiritual wellbeing. This omission was especially reprehensible given recent reports that warn of the dangers to children's rights posed by population growth and climate change. A 2023 report by UNICEF and the World Bank notes that a combination of rapid population growth and limited social protection measures have led to a steep increase in the global numbers of extremely poor children, especially in Africa and South Asia where nearly ninety per cent of the world's children caught in extreme poverty reside (Salmeron Gomez et al., 2023). Yet another report warned that almost half of the world's 2.2 billion children are at risk of experiencing 'extremely dire' conditions from the climate crisis and pollution (UNICEF, 2021).

The convergence of poverty, rapid population growth and unjust cultural norms also fosters high rates of child marriage: Recent data from UNICEF indicate that more than 700 million women alive today were married before the age of eighteen, of whom 250 million were married before the age of fifteen (UNICEF, 2014). The practice of child marriage perpetrates the sexual abuse of girls and stunts their life prospects, while contributing to the spiral of population growth, poverty and high rates of morbidity, and stunting and early mortality among children born to these girls (Wodon et al., 2017). The relationship between population growth, high fertility and the violation of children's rights is especially stark in patriarchal societies. In sub-Saharan Africa, for example, due to population growth alone, a doubling in the number of child brides is projected by 2050 (UNICEF, 2014). Sub-Saharan Africa also has the highest prevalence and largest number of children in labour, representing over half of the 160 million total – another iniquitous trend projected to rise in lockstep with population growth over the coming decades (ILO and UNICEF, 2021).

Across the world, high fertility is directly jeopardising food security, the welfare of children and other vulnerable populations and ecological sustainability. The eight Millennium Development Goals (MDGs) endorsed by the majority of UN states in 2000 failed to achieve full realisation largely due to the refusal to address the population factor: Progress toward reducing child mortality, improving maternal health and securing universal access to voluntary family planning stalled or worsened as the global population grew by approximately another billion (Starbird et al., 2016). The Sustainable Development Goals (SDGs), signed by the global community in 2015 as an update to the MDGs and, like their precursor, based on the oxymoron of 'sustainable economic growth', missed the opportunity to adopt a meaningful commitment to correct this oversight. Today, the SDGs are also off track to reduce poverty and hunger, improve wellbeing and protect the environment (Kopnina, 2020a; UN, 2023).

As noted in UNFPA's own 2022 report, there is an unplanned pregnancy crisis, with half of all pregnancies, totalling 121 million each year globally, unintended (UNFPA, 2022). Other research shows that at least 270 million women globally have an unmet need for contraception due to patriarchal and religious barriers (Kantorová et al., 2020). Yet these crises are barely acknowledged in the report. At this historic juncture, this represents a fateful oversight. Instead of unpacking the pronatalist pressures that thwart the realisation of human and nonhuman rights, and promoting a comprehensive ethic of reproductive responsibility to planet, children and future generations, the report offers the following hollow generalisation:

> Support the fertility preferences and aspirations of people: understand whether people in all income categories, at all ages and in all social groups are having the number of children they want. If the answer is no, reproductive rights are compromised (UNFPA, 2023).

This statement not only ignores the rights of children to be born into a safe and caring world, it also naïvely overlooks the fact that expressed 'preferences' for numbers of children are socioculturally shaped, if not determined, and often rehearsing dominant patriarchal norms (Campbell and Bedford, 2009; Dasgupta and Dasgupta, 2017).

SWOP 2023 prioritises economic growth over human wellbeing

Despite the report's professed concern for the inalienable right of women 'to have the number of children they want', the humanity of the women doing the reproducing sometimes appears secondary to the reproductive function as such. While the report repeatedly denounces overpopulation discussions that 'transform… wombs into legitimate sites for climate policy', it has none of the same misgivings about rhetoric that sees wombs as engines of economic growth. The neoliberal wording of such statements as, 'Higher levels of human capital can offset environmental impacts while improving productivity and economic growth' frames human beings as system inputs, while whitewashing the devastating impacts of growth on nature, on children and on a human future worth living.

The priority that UNFPA places on economic growth is evident in the report's outdated assumption that such growth will automatically advance reproductive autonomy as well as fertility decline. This theory of demographic transition, as it is known, has been largely superseded (Robinson and Ross, 2007; Campbell et al., 2013; Bongaarts and Hodgson, 2022). A recent data analysis of 136 developing countries shows that falling fertility rates between 1970 and 2000 had little or no association with changes to national economies, whether measured by GDP or household consumption (Götmark and Andersson, 2022). Rather, falling fertility rates were a *direct* response to voluntary family planning programmes that provided sexuality education, normalised contraceptive use and offered accessible and affordable services – regardless of whether economies grew, stagnated or declined. Yet the SWOP report makes no direct acknowledgement of the indispensable role family planning programmes play in the transition to lower fertility norms.

Dismissal of the population-environment connection is common to UN agencies

UNFPA is not the only UN agency that promotes conflicting messages on the connection between the human population and planetary health. While the 2022 IPCC climate-change mitigation report confirmed that population increase and economic growth are the main drivers of today's burgeoning emissions (IPCC, 2022a), those results were censored and removed from the Summary for Policymakers distributed to media outlets (IPCC, 2022b). What remained were only weak claims about the potential role of 'low-emission technologies' to mitigate climate change (IPCC, 2022b). Similarly, the latest UN Conference on Trade and Development report counsels developing countries to 'embrace green tech revolution or risk falling behind' (UNCTAD, 2023). This is disconcerting in light of recent studies that have demonstrated that reliance on so-called green technologies to reduce emissions while maintaining economic growth will not only be ineffective in countering climate breakdown, but will add more devastating impacts to our predicament (Rees, 2023).

Building these technologies at the scale needed to power current levels of economic development for a planet of eight billion, and growing, would itself require a massive ramp-up in fossil fuel consumption, as well as infrastructural buildout that destroys habitats and biodiversity. 'Green' technologies also demand mining for minerals found largely in the Global South, driving deforestation, toxification of soil and groundwater, poisoning of air, killing of wildlife, human displacement due to water scarcity and exploitative labour practices including of children (Jackson and Jensen, 2022; Kara, 2023; Ketcham, 2023). This new wave of industrial extractivism is already rapacious, but it must expand to accommodate continued population and economic growth: its next frontier is the deep seabed, the last ecosystem not yet assaulted by industrialism and which harbours rich and largely unknown biodiversity (Heffernan, 2019).

The 'clean energy transition' is poised to drive staggering assaults on a natural world already in the throes of a mass extinction. Yet that transition is excused and even celebrated with arguments that we must provide for an oversized and growing human population whose inevitability is seldom questioned. The same unquestioned commitment to growth underlies the UN's reluctance to consider reining in the most environmentally destructive aspect of humanity: the food system (Campbell et al., 2017; Crist, 2019; Benton et al., 2021). The UN's Food and Agriculture Organization (FAO)'s 2006 report 'Livestock's Long Shadow' exposed the significant contribution of greenhouse gases from animal agriculture, with the sector found to account for eighteen per cent of emissions (Steinfeld et al., 2006; Neslen, 2023). The report called for significantly reducing the scale of industrial animal agriculture to curb emissions.

But former officials at the FAO have disclosed that they received such intense backlash from the major meat-producing countries that FAO's senior leadership was forced to water down their scientific findings in subsequent publications (Neslen, 2023): the 2013 report identified the livestock sector as responsible for fourteen per cent of all climate emissions, while the 2023 model ratcheted the number down to eleven per cent. In the meantime, independent studies have found that livestock emissions could be as high as twenty per cent or even 28 per cent of the total (Twine, 2021; Xu et al., 2021). FAO data are a prime source for IPCC's climate modelling, which is clearly compromised by the interests of industrial animal agriculture and a UN body that refuses to challenge them (Neslen, 2023).

Permitting political and special interest interference within the UN, especially in today's state of emergency, demonstrates compromised institutional integrity, or even uncritical support of destructive industries. In a world in overshoot, the continued pursuit of growth is a perilous path, which perpetuates the neocolonial exploitation of disempowered people and nonhuman nature via syphoning resources from Global South to Global North and downgrading Earth's biodiversity and ecological wealth (Langan, 2018; Kopnina, 2020b; UN, 2021a). Given the UN's influence on global policymakers and the public, it must lead the way out of this terminal self-destruction and toward an ethic of living equitably within ecological boundaries (Jackson and Jensen, 2022). We urge the UN to face the reality that growth at the interconnected levels of human numbers, economic activity and technosphere is imperilling the biophysical integrity of Earth as well as human survival and quality of life.

A call for the UN to embrace and implement a new ethic of degrowth and justice

Humanity's recent historical experience has revealed that unrelenting population and economic growth have devastated nature, depleted resources, fuelled intra-human and human-wildlife conflict and undermined humanity's tenure as conditions deteriorate. We must abandon the growth paradigm and willingly shrink the large-scale variables that underpin overshoot: lower our global population by means of policies that elevate human rights and responsibilities; reduce our economic activity within frameworks of equity, meaningful work and peace; and contain the technosphere from overtaking the face of the Earth.

Reduce population

Decades of research show that providing affordable and accessible family planning and contraceptive services to all, along with education and empowerment of women and liberation of girls from child marriage, are the fundamental human rights through which fertility declines. Lowering the population hinges on instituting these rights (Robinson and Ross, 2007; Bongaarts and Hodgson, 2022; Speidel and O'Sullivan, 2023). Concurrently, we need to confront the sociocultural forces of pronatalism that have held women (and men) captive to the idea that biological procreation is obligatory and that motherhood is destiny (Campbell and Bedford, 2009; Kuhlemann, 2020; Bajaj and Stade, 2023). Reproductive norm-shifting programmes such as radio shows, soap operas and other cultural initiatives are key components of this overarching approach to combating pronatalism (Ryerson et al., 2022). This approach aims for reproductive liberation, where procreating becomes an authentic decision, choosing to be childfree will be an equally acceptable option and alternative ways of creating family – including adoption – are embraced. This freedom also opens the door to reproductive responsibility: promoting procreative choices that consider the individual rights and wellbeing not only of the parents, but also of the children to be born, human beings already in existence and nonhuman creatures within the entire web of life (Hedberg, 2020; Rieder, 2024).

The goal of a smaller human population is not about 'social engineering' or 'population control'. On the contrary, it is about understanding that there must be fewer of us so that the fundamental needs of human life – most especially food, but also freshwater, housing, basic commodities, energy and infrastructures – cease to devastate land and seas. Today, humanity demands *half* of Earth's ice-free surface to make food while industrial fishing has devastated marine life abundances and habitats (Fletcher et al., 2024). How can UN agencies, and other constituencies, rationally claim that these life-shattering metrics have *nothing to do* with human numbers?

Reduce economic activity

Redressing how economic activity fuels overshoot is more complex, given economies' fundamental dependence on both biophysical reality and social structure. The complexity of economic-driven impact demands redirection on several economic variables simultaneously (Spash, 2024). We argue for a multipronged approach: reduce the workweek; eliminate the production of luxury, throwaway and planned obsolescence commodities; reduce global trade; shrink the materials- and energy-intensive global military sector; revamp the financial system away from debt and credit; and transform how we grow food and make dietary choices.

As an overarching mandate, we need to reduce industrial extraction, production, trade and consumption. Lowering our numbers will facilitate such economic downscaling but other interventions are equally imperative. Leading ecological economists have emphasised the importance of shortening the workweek for both ecological sustainability and human wellbeing (Dietz and O'Neill, 2013; Hickel, 2020). A shorter workweek translates into lowered extraction, as well as reduced production and lower energy consumption. Shortening the workweek also allows for work-sharing, redressing unemployment.

Working less supports human wellbeing by allowing people to switch from *doing* too much to *being* more spaciously: devoting more time to non-consumptive (or less consumptive) activities like cultivating friendships, tending gardens, exercising, engaging in volunteer work and apprenticeships, and pursuing hobbies and spiritual interests. Such activities are less impactful on nature and enable human beings to explore the meaning of being alive. Cutting back the workweek will create a far less destructive economy, while fostering a civilisation that values self-realisation for all people.

Another indispensable component of downscaling is to end the production of luxury, throwaway and rapid-obsolescence products. For example, the fact that mining is still carried out for the mass production of jewellery is something that should deeply dismay us. The fact that cars, cell phones, personal computers and so on are ceaselessly produced as 'new models' should repel us. Even as we eliminate superfluous commodities and make products more durable, we need to transition from an extraction economy to a recycling economy. And since we know that recycling consumes energy, we must simultaneously work toward conserving and sharing goods.

Economic activity related to the global military establishment must be greatly curtailed. The military industry devours inordinate amounts of energy and materials. It demands extravagant funding, which if redirected to social programmes and nature protection would advance human and planetary wellbeing (Klein, 2019). This unprecedented historical moment must also spur humanity to recognise the insanity of taking militarism for granted and the sanity of transitioning to a fully demilitarised global civilisation (Crist et al., 2024).

The debt-based global capitalist economy interconnecting billions of consumers (with more billions in the wings) is the most powerful accelerator of overshoot, lacking any built-in mechanism to break its destructive spiral. The financial system – so Byzantine in its workings that no one fully understands it – hinges on the mechanism of credit, debt and the device of the credit card to 'abolish poverty' and produce middle class populations indentured, through debt, to working for the system (Lazzarato, 2012). Financial capitalism produces a fake form of wealth with *real* purchasing power, bankrolling the expansion of the technosphere at all levels (from building highways to buying personal computers) at the expense of nature's integrity, at the cost of continuous waste streams and with the bill-due constantly pushed into the future. How to revamp the global capitalist financial system is admittedly difficult to imagine within the current economic status quo. However, this should not stop us from recognising that, as the main engine of economic growth augmented enormously by the growing global middle class, it is driving the desolation of Earth.

As a last point on shrinking economic activity, we must focus on the industrial food system, which is delivering lethal blows to biodiversity, contributing heftily to global heating and planet-wide pollution and undermining human health (Campbell et al., 2017; Crist, 2019; Benton et al., 2021). The most harmful component of the industrial food system is animal agriculture, which continues to spread in tandem with the growing global middle class and the relentless pressures of animal-food industry interests. Beyond its high ecological costs and human disease consequences, industrial animal agriculture egregiously violates the basics of ethical treatment of animals. We offer a plea for an ambitious UN global initiative advocating mostly plant-based eating, which could help spur reduction of the global livestock population. This turn would free large swathes of land for ecological restoration and rewilding, deliver better health outcomes for people and reduce the violent exploitation of animals. We also need to rethink food consumption more broadly, substantially reducing processed and packaged foods and the trading of foods. From the shallow call 'to feed the world', we are invited to shift to a new sensibility of 'nourishing humanity': eating more locally, more plant-based and clean food produced with minimal industrial inputs (Benton et al., 2021; Crist et al., 2021).

Reduce and restrain the technosphere

Humanity must find a way to restrain the sprawl of industrial material culture, including infrastructures. Reducing the global population and economic activity will take us a long way in the direction of containing the technosphere and allowing expansive natural ecosystems and abundant wild plants and animals to revive (Crist et al., 2021). However, deliberately choosing to limit the reach of the technosphere, including human suburban and exurban settlements, aviation, roads, pipelines and other infrastructures, is a crucial aspect for moving toward an ecological civilisation (Laurance, 2018).

Conclusion

A commitment to downscaling the human factor on demographic, economic and technosphere fronts is imperative for transitioning to a simple, equitable and high-quality material and spiritual life for all humanity within an ecologically restored planet of biophysical abundance. Such a transition can be effected by means of honouring fundamental human rights, including the rights of children and future generations. A commitment to downscaling recognises the essential role of animals and ecologies for human physical, mental and spiritual wellness, as well as their inherent right to dignity and sufficient habitat and resources to thrive. Acknowledging that Earth is our *sacrosanct home* – not a stage for human development, resource or spaceship – lays the groundwork for promoting protected natural areas, ecological restoration, rewilding projects, agroecological farming, urban green spaces and strong legal frameworks to halt and reverse the defaunation of land and seas. We appeal to the UN to enlarge our understanding of justice to include all lifeforms, wild and domestic, and the care of their habitats and homes (Kimmerer, 2013).

The dynamic stability and vitality of Earth's ecosystems and all its inhabitants demand a major reorientation of the human imagination to respond soberly to mounting social and ecological crises. We must face the truth by grounding ourselves in humility, relinquishing planetary domination, shrinking human presence and activities, and spurring into action to reinstate kin-centric relations with the planet and its entire community of life. To move beyond the failed approaches of our current politics requires us to abandon the incessant pursuit of growth, and to embrace a sense of our shared humanity embedded within the larger web of life. We urge the UN to help lead the way.

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PEER REVIEWED ARTICLE

Evaluation of circular strategies and their effectiveness in fashion SMEs in Ghana

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Abstract

Circular economy strategies may appear practical for business but are complex in application. Country-specific situations, taking into consideration the cultural dimensions, aid the practicality of such strategies. As part of a longitudinal research, this study sought to identify and evaluate circular strategies that could be integrated into selected fashion SMEs in Ghana. An in-depth qualitative case study was adopted to engage nineteen owner-designers of SMEs through interviews and observations. The owner-designers must have formal businesses, have been running their retail stores during the last decade and operate within the two major cities in Ghana where population growth supports economic activities. Life extension strategies were adopted for the study. The indications were that the majority of owner-designers of fashion SMEs, although practicing some circular strategies unknowingly, were not motivated to formally integrate the practice into their businesses. Cost, time, labour and consumer attitudes and

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behaviour were factors considered to undermine the effectiveness of adopting and implementing circular strategies in these firms. Creation of awareness of circular strategies and models for their implementation are needed to enable practitioners to imbibe circular economy principles in fashion SMEs in Ghana.

Keywords: Fashion, circular strategies, evaluation, small to medium scale enterprises, cultural environment.

1. Introduction

The fashion industry is on a mission to remodel its production away from the linear model to contribute to preserving the environment and its social foundations for future generations (Steffen et al., 2015). The United Nations Agenda 2030 has heightened the call for fashion to intensify aligning its practices towards reduced consumption and production (SDG 12). Studies have shown overwhelming support for the Circular Economy (CE) (Accenture, 2016; Ávila-Gutiérrez et al., 2019) mainly due to its contribution towards the separation of biological and technical nutrients under cyclic industrial metabolism. The incorporation of the principles of the CE in the links of the value chain of the various sectors of the economy strives to ensure circularity, safety, and efficiency. The framework proposed is aligned with the goals of the 2030 Agenda for Sustainable Development regarding the orientation towards the mitigation and regeneration of the metabolic rift by considering a double perspective. Firstly, it strives to conceptualise the CE as a paradigm of sustainability. Its principles are established, and its techniques and tools are organised into two frameworks oriented towards causes (cradle to cradle; Fuchs, 2016; Kirchherr et al., 2017; Koszewska, 2018), which seeks to aid the use of resources in a regenerative manner (Ellen MacArthur Foundation, 2013). According to Global Management Consultancy Accenture, CE approaches have the potential to add as much as US$6 trillion to global economic growth by 2030. Apart from the economic benefits, the CE is touted as aiding employment generation and business opportunities significantly, and more importantly eliminating waste (Nijman-Ross et al., 2023) that accompanies the linear production model. Focusing on the CE principle of the 3Rs (Reduce, Reuse and Recycle) implies many materials are reclaimed for use instead of extracting virgin raw materials.

1.1 The fashion industry in Ghana

Garment production has existed for many years, but the fashion industry in Ghana is a recent phenomenon which is steadily growing. The industry is primarily composed of micro and small to medium-scale enterprises with a few large-scale firms (Ghana Statistical Service, 2016). The majority of producers cater for the domestic market, with custom-made clothes sold directly to consumers. About a decade ago, retail outlets operated by fashion firms whose owners doubled as designers emerged. Small to medium-scale firms are championing the rise of retail outlets, significantly situated in the two capital cities of Ghana. These two cities have the largest population and highest economic and social activities. As with selling seasons in Europe and America, owner-designers have predominantly adopted four selling seasons. Although these selling seasons are not weather-related, a quarterly approach is adopted to ensure that new collections are developed to bring excitement to the shop floor.

The owner-designer concept is a development that is advantageous to the practice of CE strategies since it is characterised by flexibility in decision-making as a result of direct involvement in major decisions at the design stage. Also, there is the likelihood of adapting to change more quickly than large-scale counterparts (Claxton and Kent, 2020; Di Lodovico and Manzi, 2023; Karell and Niinimaki, 2020). SMEs are seen to provide employment and economic growth, hence adopting the principles of the CE presents numerous benefits while enhancing their competitiveness. While there is a host of research especially from the global north on the fashion industry adopting a sustainable approach, particularly the CE (Nijman-Ross et al., 2023) the reverse is true of the fashion industry in Ghana. Nijman-Ross et al. (2023) identified several countries that have adopted the CE, including Germany, Finland and China, citing authors from the UK, USA, China and the Netherlands, but none from Africa. While research on garment production in Ghana is common, few have covered sustainability and the CE. James and Kent (2019) and Amankwah et al. (2023), although focusing on sustainability and the CE, did not touch on fashion businesses integrating the CE into their practices. Fashion sustainability and the CE are grey areas in Ghana. As asserted by Nijman-Ross et al. (2023), research on the CE is low but there are initiatives in some African countries such as the establishment of the African Circular Economy Alliance (ACEA), and a study carried out by the African Development Bank (AfDB). In Ghana, a report for the Tony Blair Institute for

Global Change highlighted the need for the adoption of the CE as a means of curbing waste (Ahiable and Triki, 2021). That notwithstanding, some strategies of the CE are, in the authors' opinion, practised informally.

As part of a longitudinal research project, the study presented in this article evaluates the adoption of circular strategies (CS) from the perspectives of owner-designers of SMEs, and the interventions necessary for take-up. To effectively address the issue, the research questions posed were: which CE strategies are culturally and technologically effective in selected fashion SMEs in Ghana to enhance sustainable fashion production? How do opportunities and challenges in the local environment affect the adoption and implementation of CE principles? This research significantly contributes to perspectives on CE adoption while highlighting how the local environment in Ghana impacts the prospects of CE in achieving sustainability.

2. The review

This section presents a review of sustainable strategies focusing on the CE. It presents a narrative on the adoption of sustainable approaches in Africa and Ghana in particular. It draws on the Sustainable Fashion Innovation Framework and the Sustainability Framework; and their application to the CE. These sub-themes provide a context for evaluating CSs in fashion SMEs in Ghana. It also brings to the fore how the cultural dimension shapes the adoption and implementation of specific CSs in Ghana.

2.1 The fashion industry adopting CE principles

The fashion industry globally has been operating on a linear model: take-make-dispose (Ellen McArthur Foundation, 2013). Research has pointed out waste accumulation at each stage of the garment production process (Pingki et al., 2019; WRAP, 2017; Yalcin-Enis et al., 2019). Critical to the linear model is the amount of goods sent to landfill sites (Juanga-Labayen et al., 2022; Morell-Delgado et al., 2024) after each selling season. Clothes that could not be sold become solid waste, clogging rivers and causing other environmental problems (Bick et al., 2018). In low to medium-sized economies like Ghana, solid waste is a potential environmental health hazard, particularly due to the less robust municipal waste systems (Liyanage and De Silva, 2018). Akintayo et al. (2023)

lamented the challenges of solid waste management in Nigeria, a neighbouring country of Ghana. Significant concerns are growing about landfilling garments in both developed and developing countries (Juanga-Labayen et al., 2022). Greater consciousness is required in the fashion industry to avert such excessive environmental harm and attempt to reduce reliance on virgin resources through recovery processes. Bick, Halsey and Ekenga (2018) asserted that the average American throws away approximately eighty pounds of clothing and textiles annually, occupying nearly five per cent of landfill space. As far as fashion production is concerned in Ghana, such statistics are not readily available. As the industry in Ghana is envisaging growth in the coming years, precautionary measures need to be taken, and the CE provides a potential remedy (Ahiable and Triki, 2021; Nijman-Ross et al., 2023). But how do these factors that trigger sustainable practices in the fashion industry affect developing nations like Ghana?

The fashion industry in Ghana is arguably in the developing stage where operations appear dissimilar to developed economies. Output, technology and know-how, among other things, are comparatively low (Senayah, 2018). The World Bank (2012) raised pertinent questions about the preparedness of developing countries like Ghana for green practices, including: Will technology allow developing countries to pursue a less environmentally damaging development path than industrial countries? What is the best way to manage growth with scarce fiscal resources, limited planning, and technical know-how? In practising the CE, these are key questions the operators of fashion SMEs must consider in making critical decisions.

It is easy to conclude that countries like Ghana are not at the point where vigorous sustainable fashion practices should be of concern. The industry is in the early stages of building structures to become vibrant. The World Bank (2012) identifies the flaws in the ‘grow now, clean up later’ argument. Therefore, heightened environmental concerns in advanced fashion jurisdictions should be a prompt for Ghana to develop sustainable strategies from the outset. In this regard, exploring Ghanaian fashion brands’ perspective cannot be timelier.

2.2 Factors positioning Ghana for CE adoption

Raw material production, both natural and synthetic, is known to produce adverse environmental and social impacts (Sahimaa et al., 2023; Sandin and Peters, 2018;

Tang and Ho, 2023). With a looming shortage of raw materials (Accenture, 2016), a shift from a linear to zero-waste circular cycle is critical. In this regard, the CE focuses on products designed to enable reuse, components disassembled and durable pieces reassembled into new products, worn-out parts refurbished, and material recycled as well (Ellen McArthur Foundation, 2015). The call for CE is underpinned by a rise in demand from an increasingly affluent population (Hammad et al., 2019) exerting pressure on resources (Bhardwaj and Fairhurst, 2010; Niinimäki et al., 2020). The expected growth in the world's population will be accompanied by significant growth of the middle class in developing countries. The Business of Fashion (BoF) report (Beltrami et al, 2019) envisaged that, if consumers in developing countries buy more clothing as their purchasing power increases, clothing sales may rise significantly. Ghana as a developing country could benefit from the projected growth.

The Ghana Statistical Service (GSS) (2021) report on population and housing pegs Ghana's population at 30.8 million. According to the report, there has been a continuous growth in urban population, increasing, from 12,545,229 (50.9%) in 2010 to 17,472,530 (56.7%) in 2021 with almost half (47.8%) of the increase in the Greater Accra and Ashanti regions. These two regions are also the economic hubs of the country. National population density increased by 26 persons between 2010 (103/km^2) and 2021 (129/km^2), with Greater Accra experiencing the highest increase, of 445 persons (from 1,236/km^2 to 1,681/km^2). Moreover, the age structure of the population has witnessed a shift from the domination of children (0–14 years) to young people (15–35 years). The GSS report shows that nationally females (15,631,579) outnumber males (15,200,440) by 2.8% (437,139), while in urban areas this rises to 5.0%. Also, professionals constitute less than a tenth (8.4%, 837,989) of employed persons above the age of 15, 80% of whom are in urban areas and 60% under 35 years old.

These population dimensions positively impact the economic growth of the fashion industry in Ghana. With the increase in the youthful population and a steady growth of professionals in urban areas of developing countries, consumption of fashion products is thought likely to rise by 2023 (Beltrami et al, 2019). However, there is currently (as of 2023) a lack of research on clothing sales by fashion SMEs in Ghana to corroborate this.

The steady growth of urban professionals and the rise of clothing retail require that the fashion industry in Ghana prepares to initiate sustainable waste management practices, particularly the CE. The CE principles illustrated in the waste management framework (Kirchherr et al., 2017) have been adopted by firms such as Patagonia and Nudie Jeans. Pal and Sandberg (2017) asserted that strategies like repairs and refurbishment have started worldwide and are predominantly led by niche and small-scale redesign brands. In predominantly micro, small-to-medium scale fashion firms in Ghana, key lessons and success stories could be replicated. Fortunately, disassembly, redesign and repair/alteration are traditionally practised in Ghanaian homes. As a culture of marriage in some tribes, brides are given sewing machines to enable the mending of clothes of family members so garments could be worn over extended periods and to reduce the financial burden of buying clothes regularly. Again, the huge importation of second-hand clothes in Africa (Lewis et al., 2017) and by extension Ghana, provides an enormous source of materials that could be disassembled and reused. These practices provide a foundation for formally introducing such models in fashion SMEs in Ghana.

2.3 Embracing circular strategies in Ghana

Stahel (2016) argues that Africa, and by extension Ghana, needs to build an industrial economy and therefore a transition into a circular economy will not be worthwhile. The World Bank report (2012) however, disagrees; it envisages an African economy which is robust in sustainable growth. While developing economies including Ghana seek to industrialise, they must consciously avoid unsustainable and reversible environmental damage. SMEs in Ghana must embrace the circular paradigm to avoid errors accompanying environmental, social and economic aspects of linear production, as their structures are not yet complex. While the World Bank encourages Africa to embrace sustainability, it also highlights the accompanying challenges, the lack of resources, technical know-how and the lack of sophisticated technologies. Twelve years after the World Bank report, the fashion industry in Ghana still lacks resources, technical know-how and sophisticated technologies to improve garment quality (Ghana Statistical Service, 2016; Senayah, 2018). Although the CE is achievable, there are barriers amidst economic opportunities that are untapped (Ellen McArthur Foundation, 2015). Bearing in mind the challenges associated with the practice of CE, which of the strategies might fashion SMEs adopt? According to the World

Bank report, one of the resources the local fashion industry lacks is the availability of material inputs. Can fashion SMEs recover unique materials from used clothes through disassembly for reuse or redesign?

2.4 Sustainable fashion innovation framework

Sustainable fashion innovation is a response to the linear mode. This new paradigm of imbibing sustainable fashion practices is expected to integrate the sustainable development framework (Ávila-Gutiérrez et al., 2019). To proceed with a sustainable fashion agenda requires an understanding of the concept of sustainability (Hur and Cassidy, 2019; Karell and Niinimäki, 2020). However, the sustainable development framework keeps evolving. The adoption of a framework is guided by the firm in question and the dimension of sustainability it seeks to achieve (Karell and Niinimäki, 2020). In this regard, the fashion industry has a range of approaches to sustainable fashion, including design for longevity, upcycling, slow fashion, product service systems, lean manufacturing, ethical trade and circular economy, among others (Bocken et al., 2014; Cooper et al., 2013; Ellen McArthur Foundation, 2013; Gwilt and Rissanen, 2011; Hernandez et al., 2019). However, such approaches still require further investigation as there are many overlaps (Pal and Sandberg, 2017) due to poor understanding regarding the strategies and heuristics for their implementation. For SMEs in Ghana to embrace sustainable fashion requires a clear knowledge of what the strategies are, and firms' capabilities to operationalise them.

The 'Sustainable fashion innovation framework' embeds the categorisation of impact levels (Bhamra et al., 2013; Schaltegger et al., 2012) that align with the waste management hierarchy (Kirchherr et al., 2017). The waste management strategy a firm adopts should align with the impact level expected to be achieved (Schaltegger et al., 2012). To effectively identify and evaluate existing strategies for application in the study environment, attention is given to the categorisation under the 3R (Reduce, Reuse and Recycle) framework of the CE (Ellen McArthur Foundation, 2013) to guide the selection of the strategies and their suitability for integration in fashion SMEs in Ghana.

Regarding the selection of strategies, it is imperative to consider how the materials available in the local environment influence the selection of strategies that prolong the lifespan of products made from them. Citing Lacy (2015), Fuchs

(2016) argues that if toxic resources are used to design a more reliable, longer-lasting product, it is still not fully circular. In an environment where sustainability in fashion is a grey phenomenon, awareness of what constitutes a toxic material is a challenge. In this context, considerations can be given to strategies such as adopting life extension and life optimisation, minimising resource usage and enabling easy assembly of fashion goods. In the context of the Ghanaian fashion landscape, garments produced for customers to pick up or sold at the retail store could be adjusted by either resizing, mending or redesigning. Even though this is an informal practice in Ghana, are SMEs willing to embrace CS formally as new business models; and are there any known frameworks to determine the impact levels of these businesses in Ghana?

2.4.1 Sustainability framework and the circular economy

In practising sustainability, a holistic approach must embrace all three pillars of sustainability (Environment, Social and Economic). However, for sustainable fashion, the three pillars require expansion. Kozlowski et al. (2019) argued that adopting sustainable models will require cultural and aesthetic dimensions to ensure that the people for whom the models are designed find them culturally acceptable and aesthetically pleasing to use over a long period. While arguing for their inclusion of cultural dimension to the existing sustainability pillars, Kozlowski et al. (2019) stated that sustainability concepts generally fail to differentiate among cultural systems, value systems, norms, behaviours and ideas. Culture is a significant consideration in sustainable development (Rayman-Bacchus and Radavoi, 2020; Sabatini, 2019; Zheng et al., 2021) which leads to partnerships being required to tackle the complex nature of sustainability and the CE. Incorporating the cultural dimension ensures fashion firms do not blindly adopt blanket solutions but rather consider local systems based on which sustainable circular models are integrated into their operations. Sustainable practices can be tailored to, but not captive to cultural context (Zheng et al., 2021). It is vital to adopt models through the lens of country-specific situations with considerations such as local culture, political climate, economy, and infrastructure (Kozlowski et al. 2019, Tremblay et al., 2017). These are critical factors to ensure selected models' integration and longevity.

The local production culture enables fashion SMEs in Ghana to primarily have direct engagement with customers even at the design stage. Therefore, it is fair to assume that they know their customers' cultural behaviour which could largely influence firms' willingness to practise a selected circular model. A firm's business culture must align with the customers it intends to serve to make it profitable and sustainable. CSs ideally are not a mass production approach; hence firms' willingness to participate is a first step.

Given that these SMEs produce limited editions for retail, their owner-designers, by means of their business cultural environment, can project strategies that yield mutual benefits. Waste in the fashion industry finds a remedy in the CE principles. As SMEs develop an interest in establishing retail outlets, waste accumulation is a potential threat to environmental sustainability. As a developing industry, SMEs in Ghana could formally adopt CSs that are practised traditionally by Ghanaians and may not require sophisticated technologies. However, limited research in the CE in Ghana presents a challenge to the integration of CS models in fashion SMEs.

3. Methodology

The study sought to identify and evaluate sustainable strategies and their effectiveness in selected firms with specific reference to the 3Rs espoused by the CE. To gain insight into the phenomenon, a qualitative case study approach was adopted as this paves the way for an intensive analysis of specific details often overlooked by other methods (Kumar, 2011) and to explain participants' perspectives on the subject. The study did not seek to measure but rather to explain the phenomenon. Fashion businesses with their specific brand concepts will have different meanings and approaches to the subject. These different brands will present different perspectives (Creswell, 2013) on the study. The population for the study was SMEs in the two major cities of Ghana, and sampled fashion SMEs that have owners doubling as designers, have operated formal businesses within the last decade and have retail outlets.

3.1 Data collection and analysis

A purposive sampling strategy (Maxwell, 2012) was adopted to ensure that data was collected from respondents who fit the description. Hence a snowball technique according to Cohen, Manion and Morrison's (2007) definition was employed in reaching 19 respondents; 6 from Kumasi and 13 from Accra as presented in Table 1. As data collection occurred amid the COVID-19 pandemic, recorded interviews were conducted via Zoom and telephone (9), along with 10 face-to-face interviews. Interview questions sought to find out the approach to garments that did not sell during previous seasons and whether materials could be recovered based on Research Question 1. Again, the opportunities and challenges that could influence participation in CE were of interest to answer Research Question 2. The interviews lasted an average of 21 minutes. The scripts were cleaned and coded line-by-line in an iterative manner using inductive and deductive coding techniques with the Nvivo software. To conceal respondents' identity, the owner-designers were coded alphabetically to read, e.g., 'ODA'. The results were categorised using thematic content analysis. The themes that emerged were: techniques in managing retail pieces; feasibility and consideration of adopting CS; material recovery and CS; and opportunities and challenges in practising CS. Along with the interviews was an observation of stitch types, style and embellishment techniques lending themselves to the adoption of the CSs.

Table 1. Background of selected firms

Characteristics	**Accra**	**Kumasi**
Location	13 (68%)	6 (32%)
Size	Small 10	Small 2
	Medium 3	Medium 4
Category	13 formal business	6 formal business

4. Results and discussion

This section is divided into four sub-sections. Firstly, results on techniques for managing retail items are presented and discussed. Secondly, results on the feasibility and consideration of adopting CS are presented and discussed. Thirdly, results on material recovery and the practice of CS are presented and discussed. Fourthly, results on opportunities and challenges in practising CS are presented and discussed.

4.1 Techniques in managing garments sold in retail outlets

To ensure that clothes are significantly bought during selling periods, retailers usually adopt strategies like discounting and clearance sales. Even though there are no distinct selling seasons in Ghana, retailers do have clothes hung on racks for extended periods. During this period, certain techniques are adopted to either sell or discard the clothes. To this end, respondents were asked to share their thoughts on how they managed garments during and after each selling period to avoid environmental waste, as captured in Table 2.

Table 2. Techniques in managing retail items

Approaches	**No. of Respondents**
Discount/clearance sale, redesign	3
Discount/clearance sale, donation	2
Discount/clearance sale, stored to re-introduce	1
Discount/clearance sales, pop-up stores	2
Discount only	5
Redesign and donation	1
Discount/clearance sale, redesign, donation	1
Discount/clearance sale, redesign, reuse fabrics recovered, donation	1
Discount/clearance sale, redesign, and stored to be re-introduced	1
No option applied	2
	Total: 19

Table 2 demonstrates that the conventional method of discounting and clearance sales was the most popular approach, followed by redesign and donation. These three were mainly combined. Only two respondents indicated that none of the approaches was used because of the limited items produced. Particular to CS was redesign, which appeared five times in combination with other approaches and was considered a positive development for this study. The reasons for the approaches or otherwise were captured as follows:

> We make major sales; we do the first quarter, and if we cannot clear everything, we do the second or third quarter. If some pieces did not sell, something must be wrong with them. So, do we add some beads; or do we make the sleeve short or long? After it goes to sale three times and is still not selling, we bag it up and give it to an orphanage. But rarely would we have a big bag; usually, we have about 20 or 40 pieces at the end of the year that did not even sell during clearance sales. (ODP)

A respondent mentioned that 'we bring them back and redo them; and then usually, if we cannot sell because a particular style is going out of fashion, we store them until a later date; that is the strategy'. To add to the techniques adopted, another respondent mentioned that 'mostly when we have a clearance sale, we do a 50% discount or sell at very cheap price. But if some are not sold out after the sale, I give them out or use the fabric to do something else by ripping the garment apart'.

Approaches to managing clothes at retail were adopted for economic reasons, considering the triple bottom line. None of the respondents indicated adopting a technique with environmental or social sustainability in mind. Worth noting was the redesign under the CS. However, from observation, the respondents did not consider the aesthetic and functional renewal of the clothes during the design stage. Applying CS becomes an afterthought (Gwilt and Rissanen, 2011) often resulting in material waste or excessive time consumption when disassembling or redesigning; an observation that defeats the sustainable approach. Again, the limited quantities produced also implied smaller volumes of clothes to manage at retail, hence integrating the redesign concept as a business model seemed unattractive. However, cumulative numbers over time could be significant (Williamson et al., 2006). Donated garments, which could become a useful avenue for material recovery, could be channelled through the reuse-redesign concept. With firms positioning themselves to upscale production, introducing CS provides a solid foundation as business practices are not entrenched, paving the way for flexibility (Di Lodovico and Manzi, 2023). SMEs are likely to make sustainability a core of their mission and business model (Claxton and Kent, 2020, Kozlowski et al., 2018).

4.2 Feasibility and consideration of CS adoption

Based on the knowledge of the techniques adopted to manage clothes at retail, it was imperative to interrogate the possibility of introducing circular models in the management of garments that could not be sold. To this end, the respondents were asked which of the circular strategies were feasible and could be considered for adoption per their current practices. Six strategies were presented to the respondents. It came out that twelve mentioned redesign, six repair, seven reuse, and twelve disassembly. However, a combination of strategies was indicated as feasible for adoption. The outcome is presented in Table 3.

Table 3. Feasibility and consideration of CS adoption

Circular Strategies	**No. of Respondents**
Redesign	3
Redesign, repair, disassembly	2
Redesign, reuse, disassembly	5
Redesign, reuse	1
Redesign disassembly	3
Redesign, repair, reuse, disassembly	1
Redesign, repair	1
Repair, disassembly	1
Repair	1
None of the strategies	1
Resale	0
	Total: 19

Respondents expressed their thoughts on the strategies mentioned as captured in the following excerpts:

> Sometimes we have clients who bring garments they bought or were custom-made to be redesigned because they do not fit in them anymore. So recently a client brought one of such garments with a

> piece of fabric to redesign it from the waist to the knee, and also the sleeves, so the person can wear it again. The fabric of the garment was still in good condition. (ODN)

For another respondent,

> Sometimes when customers order clothes for events like shoots or second dress for weddings, they don't wear them again. They bring them and we redesign them into simpler styles they can wear for other purposes. I do that a lot. So, we can now consciously do that because I was doing it without thinking about it or knowing it was a sustainable approach. (ODF)

One respondent also mentioned that 'Mostly we do for our customers, especially the cuffs and collars of shirts that have faded or worn out; we redo them, sometimes with different colours, textures or patterns'.

Even though most of the respondents indicated that CS was feasible, they expressed reservations about disassembly, repair, and reuse/resale. The following are excerpts on the concept of disassembly;

> The time required for ripping the seams of a garment can be used to make something that will sell three or four times more than a product made using this concept.

ODQ, ODC and ODO supported this view. This group of respondents also opposed any practice that takes away production time and derails profit. 'ODC' added that:

> Already we are running a deficit of skilled labour for the main production; if we have enough labour, and there is demand, then we can establish a unit for it.

> Strategically, it's not sustainable for any business person. Although it sounds great in theory, it cuts into your production line. We tried in the past to have a unit to do repairs but was not lucrative. You cannot charge much for alterations, but the resources that it would require;

> hiring staff, machinery etc., are not commensurate with what the client is willing to pay. Someone might say it is another channel of income, but the income level and the effort going into it, do not tally.

However, there was a positive view on the repair strategy expressed as follows: 'I think we have the demand for the repair and alterations. We usually resize for items bought at our retail shop. So, we can now position ourselves to control that consciously.'

Feasible circular strategies indicated by respondents pointed to redesign, repair, reuse and disassembly. These strategies were practised, albeit unconsciously, and hence the respondents might have gained some level of experience in practice. The unconscious practice of some CS stemmed from respondents' unawareness of the CE and its principles. For designers to consciously integrate CSs, their firms would need to understand the negative impacts of production (Karell and Niinimäki, 2020). Again, the awareness of tools (Kozlowski et al., 2019), sustainable business case drivers (Schaltegger et al., 2012) and sustainable business model innovation techniques (Bocken et al., 2014) are required for the successful adoption and implementation of CSs in fashion SMEs in Ghana. Thus, the complexities of formally practising these sustainable business models represents a significant challenge (Di Lodovico and Manzi, 2023).

The lack of awareness revealed that respondents had no idea of impact levels (Bhamra et al., 2013; Schaltegger et al. 2012) or of the collaborations that guide the practice of sustainable approaches. Again, the strategies considered feasible were informed by the cultural environment within which these SMEs operate. Limited pieces being manufactured enabled these owner-designers to quickly innovate into new styles. However, this was motivated by a focus on the growth and expansion of business, not consideration of environmental and social aspects, which were not considered profitable. Also, direct customer engagement meant consumers could walk in to request some changes needed to garments bought from the shops. In this regard, the fashion SMEs in Ghana are more likely to contribute significantly to the adoption of CE than large-scale firms. This enhances their competitiveness in receiving the needed support from policymakers. However, there are currently no known policies that enable the practice of sustainability among fashion SMEs in Ghana.

Even though owner-designers informally practised some identified strategies, some difficulties have been identified as likely to hinder their formal adoption. The difficulties expressed were time, cost, labour, consumer perceptions and readiness to pay for the cost of garments. Labour availability was one of the significant hindrances, given that the current model, as Amankwah et al. (2023) argue, struggles to get the skill set needed for production. This feeds into the needed labour to disassemble, while the main production line is in progress. In addition, the cost of paying labour to disassemble a garment and the overheads incurred in re-designing were not profitable. Finally, the consumer's readiness to buy a redesigned garment was questioned as there is a lack of research (Hur and Cassidy, 2019; Kirchherr et al., 2017) on consumers' willingness to participate in CE. While these firms directly engage with clients and have a pre-informed idea of consumers' behaviour towards such initiatives, consumer research regarding the perception of CS is lacking in Ghana.

Again, while disassembly and redesign are adaptable, stitch types and patterns were observed to be possible setbacks. To enhance the aesthetics of garments, top stitches were commonly used, making disassembly unattractive. Straight stitches afford ease of disassembly, and loose garment styles provide adequate reusable fabrics. These factors could be considered at the initial stage and not as an afterthought, as proposed by Gwilt and Rissanen (2011). Careful consideration was deemed necessary if these strategies were to be formally adopted.

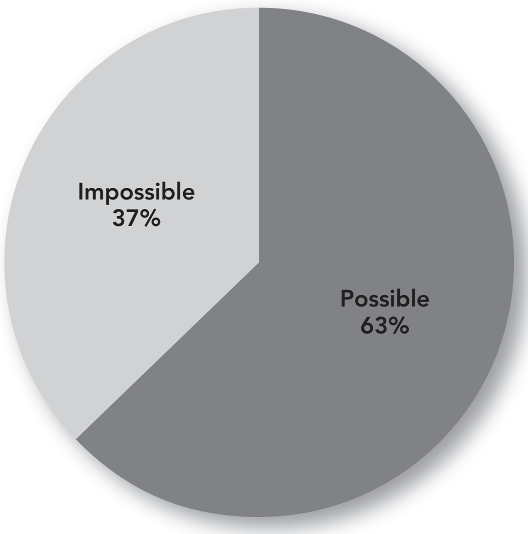
4.3 Material recovery and the practice of CS by SMEs

Material recovery requires chemical or mechanical processes. In an environment where technology is a challenge, disassembling garments through unpicking is possible and hence materials could be reused. Respondents were asked if they could recover materials either from their products or garments used by their consumers, or other brands. One out of nineteen respondents, recovered materials from garments that did not sell during the selling periods while eighteen had never considered it. Giving reasons for the lack of attempt, five respondents cited time wasting, three respondents mentioned cost, and one respondent said energy waste was associated with the disassembly process. However, ten respondents expressed the possibility of recovering materials from firms' unsold garments at the end of the selling period if the stitch and patterns lent themselves to the process.

Again, when respondents were asked if they could request their customers to bring back relatively little-used garments of their brands, all nineteen respondents were not enthusiastic about the idea. The responses given were revelatory. 'By the time they bring it, the fabric value will be low, and treating the garment will be more costly than making a new one'. Another respondent indicated that 'Here in Ghana, most people do not know how to care for their clothes; the fabrics to be recovered might not be in good condition.' For consumers to make sense of such garments, one respondent emphasised that 'Maybe post a video of how you go about the clothes and some certification to prove that the clothes had been inspected by a recognised body; that they are in good condition, etc; you have to build that confidence'.

Again, on material recovery, respondents were asked if they would be receptive to imported second-hand garments that have flooded the local market. Twelve of the respondents indicated this to be a possibility, while seven said it was impossible, as shown in Figure 1.

Figure 1. Possibility of recovering materials from second-hand. Authors' construct



Expressing their perspectives on second-hand materials, three respondents indicated that they were unaware of some fabric names, compositions and classifications. Two respondents believed that process disclosure would ensure consumer confidence, while four respondents noted that consumers would be unwilling to patronise the products if process disclosure was pursued. Similarly, in recovering materials from customers' relatively used garments, two respondents believed that pre-treating the worn garments for use in new production would be costly. However, two respondents believed that certification of the process could be given to boost consumer confidence. On the condition of second-hand products (garment / fabric), six respondents notably mentioned fabric stock or store-rejected garments as an attractive proposition for consideration. Table 4 provides a perspective.

Table 4. Respondents' perspectives on material recovery from second-hand garments

Perspectives on second hand recovery	**No. of Respondents**
Fabric composition	3
Process disclosure	2
Process disclosure renders the product unattractive	4
Costly treatment process	2
Ensuring process certification	2
Preference for fabric stock	6
	Total 19

Again, with twelve respondents indicating the possibility of recovering materials from second-hand garments, they were asked about the attractiveness of establishing a warehouse. Seventeen respondents deemed it as a welcome idea, however, with the caveat that the products must be in good condition. Some respondents had this to say: 'Industrial waste could be considered. When it comes to fabrics, we are all lacking. So, if somebody can source fabrics/garments and have an open day for sales, it will minimise direct sourcing from these factories polluting the environment.' Another respondent confirmed by saying; 'that will work because we buy fabric stock which is relatively scarce on the market and is also unique considering our brands, unlike the bulk imports coming from Asia'. Questioning the benefit of having a warehouse to stock second-hand materials, a respondent opposed earlier respondents saying, 'It is possible to have a warehouse; but as far as they are considered used clothes, for me, it's difficult'

One of the benefits of practising the CE is the economic value as more revenue generation has been associated with CE. However, for owner-designers of SMEs in Ghana, additional costs could be incurred due to low-skilled labour, uncertainty about demand and the time required to work on these items. These factors make the practice of CS unattractive and costly. Apart from the cost, material value was seen as a contention, particularly with how local consumers handle garments during the use phase. The humid environment requires that consumers wash clothes regularly. These washed clothes are continuously exposed to sunlight, which weakens the fibres and also leads to colour fading. Another important factor is the cultural beliefs and superstitions associated with transferring personal clothing to another, especially a non-family member. Environmental and cultural conditions (Kozlowski et al., 2019) were seen as significant hindrances to the reuse concept.

Associated with reuse was the concern about pre-treatment cost and process certification to boost consumer confidence. While the transparency of the process is one of the key indicators in sustainable strategy practice in developed countries, as championed by the Global Reporting Initiative (GRI), the majority of respondents believe process disclosure would make circular products rather unattractive to the consumer, bringing the element of culture into play. The concerns regarding disclosure confirm Di Lodovico and Manzi's (2023) observation of the difficulty with transparency when it comes to sustainability practices. The lack of regulations exemplified by the impact level frameworks (Bhamra et al., 2013; Schaltegger et al., 2012) hampers the practice of the CE as owner-designers have no guiding principles to relate their processes to the attainment of sustainability. A level of awareness among these producers and customers is necessary for imbibing the sustainability concept, justifying the assertions by Hur and Cassidy (2019) and Kircherr et al. (2017) about the need for designer and consumer awareness creation.

From the perspective of the study of the environment, material recovery for reuse is possible with imported second-hand garments or fabric stock. Reusing garments from second-hand apparel – through a redesign strategy exists among some firms and confirms the ease of adopting a recovery strategy. The challenge is sourcing these second-hand garments in the required volume, and scouting for preferred pieces is time-consuming. To this end, establishing a warehouse to facilitate the sourcing of rare pieces was welcomed. In other jurisdictions such as Brazil, textile banks are providing the bridge between manufacturers, waste management companies, fashion designers and fashion firms to enable stocking, sourcing and reusing of fabrics. Collaborations with textile firms overseas could enable direct sourcing of required quantities in assorted fabrics for warehousing. For SMEs typically producing smaller quantities, product exclusivity is important; warehousing rare fabrics will add to their competitiveness while contributing to solving environmental issues.

However, second-hand garments have been a threat to environmental health, especially in countries that have difficulty managing solid waste. Apart from local challenges with waste management, transporting the garments impacts negatively on climate health (Morell-Delgado et al., 2024). Jacometti (2019) emphasises high fuel consumption and significant emissions of greenhouse gases as a result of the transportation of goods. While these are major issues with second-hand garments, the government of Ghana has yet to put in place policies that guide the creation of products sustainably.

4.4 Opportunities and challenges in practising CS

To ensure that SMEs embrace circular strategies, the study sought to find the opportunities that can be harnessed to enhance participation. It was gleaned from the data that, even though all the respondents ran retail shops, sixteen respondents had regular direct engagement with end customers by running retail and providing custom-made products. The advantage of direct customer engagement was seen as a starting point, as summarised by a respondent; ‘In our small way, we have to play our role, because definitely, we have contact with the client, and what we are talking about goes back to the client.’

Having indicated the feasible CSs as shown in Table 3, and the opportunities available, it became necessary to know the challenges that may come with consciously adopting and implementing a strategy. Most of the respondents reiterated considering redesign, reuse and repair. However, the concept of

CS was new to them and, though they practised unknowingly, certain factors needed to be examined, and are summarised as follows; 'The challenges are more of capacity and awareness on the part of consumers and willingness to pay for service.' To add to capacity and awareness, a respondent added that; 'We are still looking out for labour, get a bigger space, so we can adopt and implement a sustainable strategy. Once that structure is in place, we can be conscious about it.' Again, another hinted that; 'In the first place, we need to get a design model that we can use for the implementation and then probably get the market base to hold on to that production level for a long time'. To consolidate the views stated earlier, one respondent highlighted that; 'It's just the know-how. We are not in the sustainability business, so we may not know how to go about it. We are familiar with the concept, but how to put it in a proper structure will be our challenge.'

It came to light that, for the majority to get involved in practising CSs, six respondents indicated that there should be mandatory participation so it does not become an individual initiative, with the government providing support systems; 'so this is like a collective side of things; we all can decide to have a level of sustainable fashion value or practice. I think that will also help. It can even be compulsory.' As there is no compulsion for garment producers to practice sustainably, a respondent shared that, 'At this point, I doubt if I can do that unless everybody is on board.' This assertion was supported by another, who opined that, 'It must be implemented so that it's not an option anymore, so it becomes a law with legislative backing.' A respondent brought two dimensions that could aid effective implementation: 'I think if the market is made for it, it becomes easier for everybody to practise. Again, currently, what the government puts in place does not fully support businesses such as fashion to engage in sustainability.'

Fashion SMEs in Ghana have the advantage of working closely with their customers on CE principles. This is very important as it encourages consumers to share their thoughts on what is produced for them and how (Kozlowski et al., 2019). Owner-designers have the opportunity to engage their customers more accurately than relying on consumer surveys. The CS integration is critical at the design stage. The issue of afterthought, as noted by Gwilt and Rissanen (2011), could largely be avoided; this will promote more accurately tailored products, hence reducing dissatisfaction accompanying mainstream products. However, the practice of CE principles comes with challenges. There is no strategy for integration, as advanced by Bhamra et al. (2013) and Schaltegger et al. (2012). Some respondents advocated mandatory participation; a defensive approach, to ensure everyone is on board. In a space where little is known of sustainability (James and Kent, 2019; Amankwah et al., 2023) and regulation is non-existent, designers have little motivation to adopt CSs. The respondents practising some forms of strategy were not aware of CSs to enable a conscious practice, a situation that requires attention. Adopting any of the approaches needs to be carried out in tandem with a model for implementation to achieve successful integration. Currently, structures are not in place for an initial take-off. The World Bank's (2012) statement that Africa, and for this study Ghana, lacks resources, technology and technical know-how are still pertinent.

Summary of findings

The major findings emanating from the study are that owner-designers practise CS such as disassembly, redesign, reuse, repair/alterations unknowingly, due to their lack of awareness of the CE principles. Regarding Research Question 1, these strategies do not require sophisticated machines to operate. The awareness created by the informal practice, coupled with the application of less sophisticated technology represents an opportunity. However, the unattractiveness of formally integrating CSs in fashion SMEs in Ghana is due to cost, time and labour, and the lack of policy direction by the government to encourage adoption and implementation. Also, respondents' impressions based on regular interactions with consumers throw some doubt on consumers' willingness to accept products made with material recovered from used clothes. Again, non-consideration of CS at the initial stage of design makes life extension strategies difficult to adopt. There was no indication of an existing model to help fashion SMEs understand the impact levels of strategies they might wish to adopt. A considerable literature on sustainability and the CE is available concerning the West and the same is now required in Africa, and (in respect of this study) in Ghana in particular, to increase understanding of the concept, its application and implications.

5. Conclusion

Fashion production is a commercial activity focused on the economic dimension, and, until recently, has relegated the social and environmental dimensions to the background. As it is a basic human necessity, the growth in population, particularly in the two major cities in Ghana, will require an increase in the production and consumption of clothes. The steady rise in designer clothing retail outlets meeting the demands of urban professionals will further add to the growth of the clothing industry, potentially exacerbating existing waste management issues. When a growth in consumption is unavoidable, then a circular perspective might provide a viable strategy to achieve sustainable consumption and production. Evaluating a firm's current process for sustainability helps to identify lapses and the sustainable circular strategy a firm can adopt to bring value. Based on research questions proposed for the study, life extension strategies such as Redesign, Repair, Reuse and Reduce are informally practised. These strategies require basic production equipment and are informal clothing care practices of the average Ghanaian. Regarding challenges and opportunities – internally, CS could be formally introduced to fashion SMEs in Ghana, supported by experiences gained through informal practices of some strategies and direct consumer engagement over the years; externally, adoption could be hindered by cultural beliefs and attitudes of local consumers as opined by respondents. However, effective implementation is dependent on government policies towards the achievement of sustainability in the coming years. Sensitisation efforts for awareness creation and a model for implementation are critical factors that must be addressed to provide the enabling environment for fashion SMEs in Ghana to operate sustainably. It is fair to say that the principles of the CE are not new to Ghana, but the dimension of environmental sustainability is. The effectiveness of CS in fashion SMEs in Ghana largely depends on understanding the relationship between practices and sustainability. As a new phenomenon, efforts from the government, industry practitioners and the citizenry are fundamental to understanding the complexities and roles of all stakeholders towards the success of CE in Ghana. Collaborative efforts from all stakeholders (Di Lodovico and Manzi, 2023) are required to tackle the complex nature of sustainability and the CE to enhance the environmental and social health of communities.

Study limitation

Consumers' exclusion from the study stems from the basis that, with CE principles, consumer participation is largely influenced by the willingness of fashion SMEs to provide service. Hence, as a new phenomenon in the Ghanaian fashion industry, owner-designers' perspectives were deemed essential to trigger conversations and subsequent research into consumer perspectives and government policies required to aid the adoption and successful implementation of the CE in Ghana.

Declaration of conflict of interest

The authors declare no conflict of interest with the study.

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PERSPECTIVE

Groundwater: sinking cities, urbanisation, global drying, population growth

John E. Pattison[1] and Peter Cooke[2]

Abstract

An examination of a few examples of aquifer use shows the importance and fragility of groundwater, with poor management leading to over-extraction by individuals and authorities producing subsidence – sinking cities. Freshwater is one of our most precious resources and it is rapidly disappearing, leading to global drying. At the same time, the global and urban populations are increasing, with civil unrest increasing due, in part, to freshwater shortages. The increasing global population and global urbanisation are driving an increase in water use, restriction of aquifer recharge and increased aquifer pollution. It is argued that urban population growth with attendant increased water use, combined with climate change and poor management, is significant in water stress. Particular attention must be paid to the effect of rising populations on local water resources, especially groundwater, and the knock-on effect on urban sustainability.

Keywords: groundwater over-extraction, subsidence, infrastructure damage, population growth, urbanisation, urban sustainability.

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Introduction

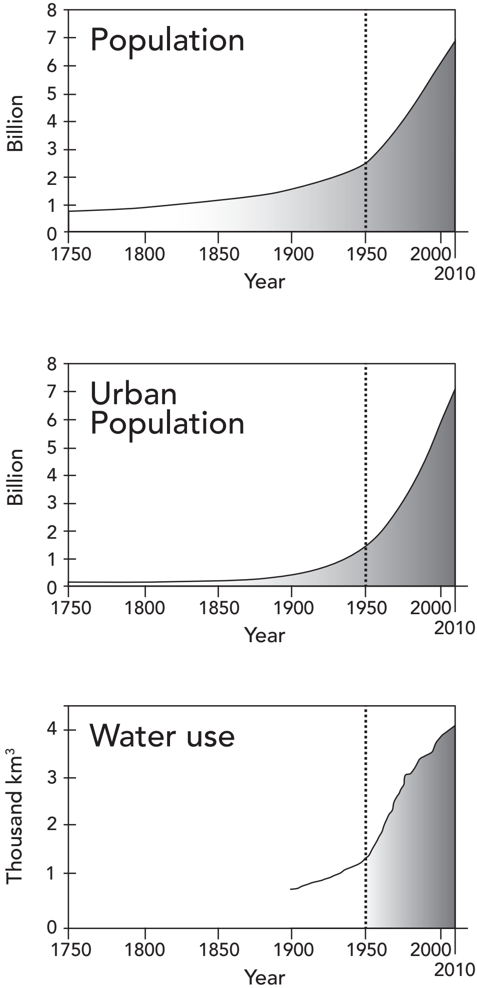
Global warming receives considerable media attention as an urgent major global issue. A visible consequence of global warming is the melting of glaciers and polar ice, resulting in rising sea levels. Consequently, some low-lying islands and coastal communities are threatened with being submerged under the rising sea. Interestingly, there are communities under a similar threat of being submerged owing to a process unrelated to global warming but seldom discussed – some cities are sinking. The reason for this second phenomenon is indisputably related to the increasing number of people in these communities using groundwater from underlying aquifers. Graphs showing the rapid increase in global water use (Figure 1) and the rapid decline in global freshwater resources (Figure 2), at the same time as the global and urban populations are rapidly increasing, communicate a strong message, but do not convey the complexity of the situations that underlie the graphs, particularly in the case of freshwater from aquifers.

There is often mismanagement and indecision leading to problems such as aquifer depletion and sinking cities with damage to civil infrastructure, corruption and civil unrest. Given the increasing global population and global urbanisation driving the increase in water use, the restriction of aquifer recharge and increased aquifer pollution, this article considers whether the global and urban water cycles are sustainable for the current and future populations and how they impinge on urban sustainability. After outlining the nature and importance of groundwater, a few examples of aquifers and their contexts are briefly described. Issues concerning sinking cities, urbanisation, global drying and the difficulty of predicting future populations – global and urban – with any certainty are then considered. It is argued that regional population growth with increased water use, combined with climate change and poor management, is significant in water stress.

Groundwater

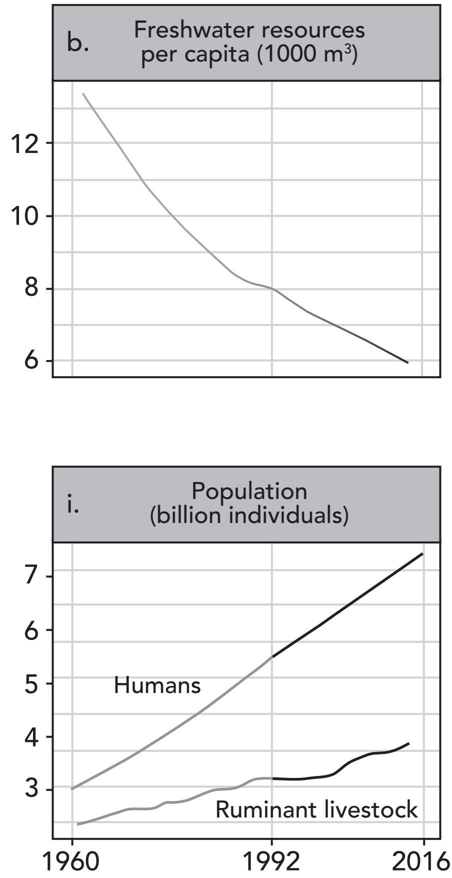
Groundwater is the water found in soil pores, rock formation voids and fractures located beneath the ground surface. A volume of below ground-level, unconsolidated rock is called an aquifer when it can provide a usable quantity of water, while the depth below ground-level at which the soil pores and fractures and voids in the rocks become completely saturated with water is called the water-table. Groundwater is naturally recharged by surface water percolating down from rain, streams and rivers; it may discharge from the ground-surface naturally

Figure 1. Trends from 1750 to 2010 in globally aggregated global and urban populations and of global water use. Water use includes agricultural, domestic and industrial uses



SOURCE: AFTER STEFFEN ET AL. 2015

Figure 2. Trends from 1960 to 2016 in globally aggregated freshwater resources per capita and of global human population



SOURCE: AFTER RIPPLE ET AL. 2017

at springs and seeps. Evaporation can also cause loss of water from an aquifer, especially in arid regions. Groundwater is pumped for agricultural, municipal and industrial purposes by constructing and operating extraction wells, as it is often used for public water supplies because it is cheaper, more convenient and less vulnerable to pollution than surface water. However, if more water is extracted from an aquifer than is going in, it will eventually run out, leading to dire consequences. Groundwater may be polluted by improper disposal of industrial and domestic wastes on land, overuse of agricultural chemicals on farms, dissolving of soluble salts from the rocks through which the water passes, or seawater intrusion. The main pollutant salt is sodium chloride, but others, some hazardous to health, such as those of arsenic (Podgorski and Berg, 2020) and uranium (Riedel and Kubeck, 2018), may also occur. Pollution may also be microbial, particularly with faecal bacteria from septic tanks and crop irrigation with untreated effluent (Ferrer et al., 2020), which may lead to diarrhoea and malnutrition.

Groundwater makes up ~30% of the world's freshwater supply, which is ~0.76% of the world's water; including oceans and permanent ice (WSS, 2018). Groundwater is a valuable resource that can serve as a natural buffer against surface water shortages since its global storage capacity is about equal to the total amount of freshwater frozen in snow and ice, including at the north and south poles. The largest users of groundwater (in 2010) were, in descending order, India, USA, China, Pakistan, Iran, Mexico and Saudi Arabia, which accounted for 74 per cent of global groundwater usage (Berne et al., 2020). The Nubian aquifer in Northern Africa (below most of Egypt and parts of neighbouring Libya, Chad and Sudan) is the largest aquifer system in the world being just over two million square kilometres in area. The Great Artesian Basin in central and eastern Australia extends to almost two million square kilometres, while the Guarani aquifer in central South America (below parts of Argentina, Brazil, Paraguay and Uruguay) covers ~1.2 million square kilometres. By analysing the trace elements in groundwater, hydrologists have determined that water extracted from aquifers may be more than a million years old.

Similar to surface water, aquifers have been over-used and polluted in many places, but their invisibility leads to mismanagement. Aquifer capacity is hard to estimate and water management organisations typically ignore effects that won't materialise during their term of office (three to five years), ignoring the decades or centuries of time delays inherent in groundwater's dynamic response to development. Groundwater extracted from insufficiently recharged aquifers, can severely damage both terrestrial and aquatic ecosystems. Subsidence is the collapse of the ground above when too much water is removed from the underground, decreasing the occupied space below the ground surface. Damage at the surface is exacerbated by the development of large features such as fissures and sinkholes, in addition to uneven settlement. During the collapse, sand and silts may move into the spaces previously occupied by water decreasing the volume of space that water can reoccupy when the aquifer is being recharged. Subsidence, caused by the increasing extraction of groundwater due to growing populations, is a problem globally. A world map of land subsidence has recently been published (Herrera-Garcia et al., 2021) and may be used to visualise the subsidence in any area of interest. It shows that nineteen per cent of the global population, and twelve per cent of the global gross domestic product, face a high probability of subsidence.

The World Health Organization estimates that a healthy person needs between fifty and a hundred litres of freshwater a day, depending on their cultural practices (Reed and Reed, 2013). However, there is a water crisis in many regions of the world, particularly in the poorest regions, and the problems will progressively become global. There are three inter-related crises: safe water access, water quality or pollution and water scarcity, the last being the pre-eminent problem (Lall et al., 2008). There is widespread scientific agreement that population growth and unsustainable consumption are the main drivers of the current growing scarcities of freshwater (Bradshaw et al., 2021; Crist et al., 2022). Freshwater has been a scarce resource historically and conflicts over water go back about 5,000 years (Angelakis et al., 2021). Predictably, severe mismanagement by some cities and countries will cause excessive migration and possibly lead to water wars in the future (Parker, 2016). It is also generally acknowledged that the recent civil unrest in Iran had a water shortage component (Dehghanpisheh, 2018). Even within a single country, different aspects of water resources may be managed by different government agencies, causing internal power conflicts and inefficiencies (e.g. Davies, 2019).

Examples

The following examples will show the complex situations related to regulation of groundwater, and water in general, faced by governments and managers.

Beijing, the capital of China, with a population of more than twenty million, has no major river in its vicinity and rain is unreliable with frequent droughts. Tens of thousands of wells in and around Beijing have dropped the water-table of a large aquifer under Beijing. There are regulations on their use, but they are inconsistently regulated or enforced so that areas of Beijing are sinking 11 centimetres per year (Chen et al., 2016). Total annual water use was 3.6 billion cubic metres, whereas freshwater resources provided only ~3 billion cubic metres before 2015. A South to North Water Diversion canal and tunnel system of 2,400 kilometres from the Hann River was completed in 2015, to bring 45 billion cubic metres of water to Beijing each year to overcome its water shortage (Chen et al., 2020). Simultaneously, plans were announced to phase out 367 wells, and programmes introduced to improve pollution control and treatment, and reduce freshwater use in industries, farms and households. It has been proposed that Beijing be moved further south to more reliable water sources.

Greater Mexico City is built on an ancient lake-bed in a mountain-ringed basin more than 2.1 kilometres above sea level, and has a population of ~20 million. The city requires water at a rate of about 60 cubic metres per second, of which about thirty per cent comes from distant rivers and lakes, and the rest from a vast underground aquifer that is being depleted at a rate faster than it is being replenished (Kahn, 2018). Consequently, the city is sinking at a rate of up to 50 centimetres per year due to groundwater extraction, with surface fissures occurring around the city. For five months every year there is a lot of rain which, instead of recharging the aquifer, runs into a massive drainage system to prevent flooding. As the city now sits ~2 metres below neighbouring Lake Texcoco, flooding has become a major concern. The city has sunk ~9 metres in the last century, and it is estimated that in the next century and a half, sections of the city could drop by as much as ~20 metres and parts outside the city by up to 30 metres (Chaussard et al., 2021). Due to different sections of the city subsiding at different rates the built environment reportedly looks like a surrealist painting with everything appearing twisted and tilted (Simon, 2021). Damage to the metro railway has already caused an accident and more are predicted (Kornei, 2017). Mexico City is also subject to occasional earthquakes. In 1954 pumping was banned in the city centre, but not in the metropolitan areas. The subsidence in the city centre stabilised, but is still a major problem in most parts of the metropolitan areas. Because of damaged water pipes, nearly forty per cent of water is wasted, such that the eastern section of the city has only about an hour of water supply a day during the rainy season and can go dry for months without water during the dry season (Kahn, 2018). The quality of the water is also poor because of contamination from broken sewer pipes. It is more economical and common to use water-carrier tankers to transport the water directly from the aquifer to its place of use. The repair cost is much larger than after a severe earthquake with no end result as the city continues to sink. Mexico City has spent billions of dollars on flood control; however, this has not helped the city's water shortage or sinking problems. Little water is recycled or used to recharge the aquifer.

Jakarta, the Indonesian capital, with a population of ten million, sits on marshy land on the coast of the Java Sea, with thirteen rivers running through it, and is subject to frequent flooding from both the rivers and the sea. The city does not pipe in enough drinkable water, and its rivers are highly polluted, so Jakartans rely largely on wells which extract groundwater from shallow aquifers, leading to subsidence. It is one of the fastest sinking cities in the world (Lin and Hidayat, 2018) and is sinking faster than the sea-level is rising. Areas of north Jakarta, including the seawalls designed to protect them from flooding, are falling ~25 centimetres per year; almost half the city is already below sea level, and some areas could be totally submerged by 2050, notwithstanding the presence of seawalls (Andreas et al., 2018). Other parts of Jakarta are also sinking but at slower rates, varying between 1 and 15 centimetres per year Attempts by the authorities to regulate groundwater extraction have failed; illegal extraction is still common. The problem has been aggravated by the sea level rise due to global warming and the rapid growth of new apartment blocks, shopping centres and government offices which increase the risk of disastrous flooding. Despite heavy monsoonal rain, the rainwater is drained away and does not recharge the aquifer because 97 per cent of the city is covered with concrete and asphalt. The national capital, Jakarta, will relocate to Kalimantan (Indonesian Borneo), according to a statement made by the President Joko Widodo in August 2019 (Lyons, 2019). Nonetheless, Jakarta will remain the financial and commercial hub of the country, and the majority of its residents and industries are expected to remain in Jakarta and will still require freshwater. Unfortunately Jakartans have become complacent and have adopted a fatalistic attitude to the sinking of their city (Lin and Hidayat, 2018).

Manila city, the capital of the Philippines, has a population of nearly two million and is located on relatively flat, low coastal flood plains on the eastern shore of

Manila Bay, Luzon Island. The Greater Manila Area includes the built-up areas and some rural areas around metropolitan Manila and has a population of >28 million. Most of the region has a tropical wet and dry season. In the wet season it rarely rains all day, but heavy rainfall occurs during short periods. The surface reservoirs are too small to store enough of this rain for agriculture, fish ponds and domestic needs during the dry season. The Pasig River flows through the middle of the city to Manila Bay; however, it is reportedly one of the most polluted rivers in the world. Groundwater is extracted from a number of aquifers in the delta plain and is used for drinking by about fifty per cent of the population (Mirano, 2019). Fishponds, a large industry in the coastal areas of Manila Bay, use large volumes of groundwater to replace the water fouled by overfeeding. Due to excessive unregulated groundwater extraction, areas of metropolitan Manilla are sinking at up to 10 centimetres per year (Eco et al., 2020). Areas in metropolitan Manila sunk from 70 centimetres to 135 centimetres over the thirty years from 1979 to 2009. The rise in the sea level due to global warming is estimated to be ~0.3 centimetres per year, making it the lesser problem for coastal communities suffering from subsidence. Manila is exposed to many natural hazards such as earthquakes, floods, landslides, tsunamis and typhoons; it is surrounded by numerous active fault systems, and has been ranked as the second riskiest capital city after Tokyo to live in. Flooding is endemic in the Greater Manila Area because waterways are blocked by human rubbish and volcanic debris, and constricted by structures because of poor building regulations or their implementation (Mirano, 2019). Numerous ground fissures have emerged in areas away from the coast, causing extensive damage to overlying structures. Although neither natural nor man-made land subsidence is yet understood or acknowledged in the Philippines, local, relative sea level increase from these sources can occur far faster than the global sea-level rise (Rodolfo and Siringan, 2006). Work to clean-up the Pasig River commenced in 1989 but was ineffectual with the executive director being dismissed in 2019 for alleged corruption (Gita-Carlos, 2019).

Venice, Italy, is located within the Venetian Lagoon at the northern end of the Adriatic Sea, and is notorious for its regular flooding. Although the residential population of the historic island city was only 53,000 in 2019 (before Covid), and is decreasing, the population of greater Venice (including the neighbouring mainland boroughs and other lagoon islands) in 2019 was 636,000, and is growing (PopStat, 2023). In addition, the annual tourist population in 2019 was 5.523

million and is also increasing (Imboden, 2023). Venice has, since its beginning, obtained freshwater from an underlying coastal aquifer system, as well as by collecting rainwater (Tosi et al., 2014). Before the 1960s, the water extracted from the aquifer had been replenished naturally. However, over-exploitation during the 1960s, especially by an increasing population, lowered the water-table alarmingly. In the 1970s, the authorities closed many wells, and the water-table appeared to stabilise. Freshwater is now mainly supplied by aqueducts from nearby mountains. More accurate measurements in 2012 revealed that Venice is still slowly sinking (Bock et al., 2012) because of two other factors in addition to the compaction of the aquifer. Venice was built on marshland. The buildings sit on top of more than ten million 25-metre-long tree trunks forced into the marshlands to reach the more solid sedimentary clay below, forming pile foundations (Mat, 2020). Although these piles have proven to be excellent for their purpose, they are not perfect and buildings are very slowly subsiding due to their extreme weights. In addition, the Venetian Lagoon sits on the Adriatic tectonic plate that is slowly subducting beneath the Eurasian plate causing everything on it, including Venice, to slowly lose elevation (Devoti et al., 2002). Venice is estimated to be sinking at a combined rate of 1 to 2 millimetres per year, which is substantially less than when groundwater was being extracted (Bock et al., 2012). Nevertheless, apart from a ~110 mm rise in sea level, natural processes and groundwater extraction are believed to have played a part in the estimated 120-millimetre subsidence of Venice throughout the course of the twentieth century. In the next twenty years, the city and surrounding land is estimated to sink by ~80 millimetres relative to the sea. Flooding has been exacerbated by poor management (Mat, 2020). The building of massive flood gates designed to isolate the Venetian Lagoon from the Adriatic Sea was commenced in 2003. The project, however, has been plagued by controversy and political scandal, and has run continually over budget; in 2014, 35 people were arrested, including the mayor and a former governor of the region, in connection to funding irregularities (Harlan and Pitrelli, 2019).

Greater Tehran, capital of Iran, has a population of ~16 million and has a cold semi-arid climate; rainfall is highly seasonal with a short rainy season leaving the land hot and dry for most of the year. Greater Tehran is supplied by surface water from dams, as well as by groundwater (Ravilious, 2018). Tehran's aquifers have been severely depleted owing to drought, a growing population, urban and industrial development, and irrigation of nearby agricultural land. Because of inefficient practices, a large part of the water used in agriculture is lost via evaporation. Further, the average Tehran resident uses 325 litres of water per day, making domestic water consumption in the country seventy per cent above the global average. Notably, the average groundwater level in Tehran decreased by ~12 metres from 1984 to 2011. A recent study (Haghshenas and Motagh, 2019) found significant subsidence in ~10% of the city centre and in many satellite towns and villages in Tehran's southwestern region: with rates exceeding 25 centimetres per year in the western Tehran Plain, which is a mix of Tehran's urban sprawl, satellite towns and agricultural land, and 22 centimetres per year to the southeast of Tehran city. The effects of Tehran's sinking are seen in uneven streets, shifted curbs, cracks in walls and tilted buildings. In addition, huge fissures, several kilometres long and up to four metres wide and deep, have appeared in the Tehran Plain to the southeast of Tehran – some of these are threatening to collapse power-transmission lines and buckle railway lines. In and around Tehran, there are areas containing about 250,000 houses,120 kilometres of railway lines, 2,300 kilometres of roads, 21 bridges, 30 kilometres of oil pipeline, 200 kilometres of gas pipeline, and 70 kilometres of high-voltage power lines, which have substantial subsidence (Ravilious, 2018). This infrastructure will be badly damaged by Tehran's continuous subsidence unless appropriate groundwater management is put in place. Unfortunately, efforts by the government to control groundwater extraction are failing. Some 30,000 unlawful wells are thought to be still operating throughout Greater Tehran, despite the fact that ~100,000 illegal wells have been shut down in Iran (Ravilious, 2018). Another problem is the pollution of groundwater caused by industrial and municipal wastewater. In the past, the Iranian government's main concern was to prioritise the building of dams (Madani, 2014). However, this approach is no longer appropriate as the total storage capacity behind Iran's dams now exceeds the water potential of its rivers. The government now plans massive investments in seawater desalination. Some analysts believe that the continuing water crisis has been a significant factor in the growing civil unrest in rural areas (Dehghanpisheh, 2018). A decision to move the capital from Tehran was made in 2009, but progress has been very slow (Tait and Hoseiny, 2009).

In addition to the aforementioned examples, many other cities are concerned about their rapidly depleting aquifers, which are or may commence sinking, or may become contaminated by sea water, such as Gaza City and Brasilia.

Gaza City, in the narrow coastal Palestinian Gaza Strip, with a population of ~2 million, has negligible surface water. It relies almost entirely on a large coastal aquifer that stretches along the eastern Mediterranean coast from the northern Sinai Peninsula in Egypt, via the Gaza Strip, into Israel covering an area of 18,370 square kilometres (UNESCWA, 2013). The ground water originates from inland recharging areas and generally flows towards the sea where it discharges. However, the Gaza Strip extracts only ~11 per cent of the total water extracted from the aquifer, with Israel and Egypt taking the greater proportion. Continued over-extraction has led to lowering of the water-table, causing seawater intrusion. Additionally, pollution from untreated sewerage and agricultural return flows has severely impaired water quality, with the UN warning that >97 per cent of Gaza's water is unfit for domestic use (Khatib, 2017): the residents of Gaza have relied upon bottled water for many years (Wade 2023). Reconstruction after the current Hamas-Israeli war ceases will provide an opportunity for the Gazan government to rebuild the water and sanitation systems. Though the problem is exacerbated by sanctions, it shows what happens because of overpopulation and poor management of a limited resource. Unfortunately, due to political constraints there are no formal or informal agreements for the optimum use of the aquifer.

Brasilia, the capital of Brazil, has a population of ~4 million. Water is obtained from dams and the Guarani aquifer beneath Brazil. Decreasing rainfall, low level of dams and rapid and disorderly growth in Brasilia have caused occasional water rationing. It is ironic that Brazil is nearly half the area of South America, with heavy rainfall in the Amazon rainforest, and yet it suffers from occasional droughts. This is primarily due to the deforestation of its rainforest, which has changed the weather pattern in Brazil causing areas to become drought-prone (Perugini et al., 2017). The Amazon River and its tributaries have become polluted with rubbish and sewage in addition to the topsoil washed down from deforested areas (Ribeiro, 2018). Heavy extraction of groundwater continues, especially for irrigation, and is rapidly becoming politicised with its control becoming increasingly controversial.

Discussion

These examples show that each individual situation is complex. Importantly, these cities face many other environmental problems that governments consider more urgent, such as incessant flooding, hurricanes, tornados, earthquakes, volcanic eruptions and the like, all causing damage to infrastructure incurring high repair costs. However, the most important common factor for water sustainability is the increasing populations that require fresh water for domestic, industrial and agricultural uses. Personal and national self-interest is evident, as are mismanagement and possible corruption. Freshwater is wasted on water-hungry crops such as cotton and rice. Due to their invisibility, aquifers are often overused and not replenished because of lack of rain or draining rainwater out through stormwater systems. Better management of freshwater is urgently required in order to avoid further subsidence and civil unrest.

Sinking cities

It is interesting that many coastal cities are experiencing a rate of subsidence, and hence, flooding, which is greater than the rising sea-level due to global warming. Subsidence is a global problem: it reduces aquifer-system storage capacity, causes earth fissures, damages buildings and civil infrastructure, and increases flood susceptibility. The only known method to prevent subsidence is to use less groundwater, and to rely mainly on surface water – a remedy which is extremely difficult to enforce when many people own their own wells. Attempts to recharge aquifers may not be successful and may possibly decrease the volume of the aquifer permanently. Further, natural recharging is a slow process owing to the long time it takes for water to percolate from the ground surface down to the aquifer. In many cases, the immediate needs for freshwater are considered more important by governments than long term sustainability, and it is optimistically hoped that rain will eventually recharge the aquifers and reduce subsidence. An attitude of do nothing and hope that the problem will go away or be tackled by later governments frequently prevails, often resulting in poor management of groundwater (Rodolfo and Siringan, 2006; Diamond, 2011; Dehghanpisheh, 2018; Mat, 2020).

Urbanisation

In 2020, 56.2 per cent of the global population was urbanised and it is predicted that by 2050 about 68 per cent of the developing world and about 86 per cent of the developed world will be urbanised (UNDESA, 2019). The impact of urbanisation on society, the economy and the environment is immense, and it offers the promise of sustainability with more efficient use of resources. Urban population growth is due to three factors: local fertility; international migration, especially from neighbouring countries with internal conflicts; and rural-to-urban migration for those in search for a better quality of life. But unplanned migration into areas often results in the rapid grown of slums and shanty towns and the benefits don't materialise.

It is a general problem that, as cities grow, surface water is often directed to flow away from the city by storm water systems to avoid flooding, while any prior-existing natural drainage channels and swamp-land are drained and built upon so that recharging of aquifers will no longer occur even though there may be sufficient rain. The denser the population, the more problems there are with maintaining the aquifers. Sustainable water drainage and aquifer recharging systems should be planned before urbanisation takes place; if undertaken afterwards to revitalise an area, these often cause preventable social upheaval.

Unfortunately, it is often considered a waste of resources by profit-oriented companies to clean up their pollution, including any that will seep down to an underlying aquifer, unless prosecuted and fined (Lall et al., 2008). A recent study found that urban megaprojects in south-east Asia threaten freshwater justice for local communities (Hawken et al., 2021). They concluded that large scale urban initiatives are typically the opposite of effective urban planning: They negatively affect regional water systems, and their sponsors and funders take little responsibility for these effects. When large sums of money are involved in any major development project, there is always the possibility, or at least a suspicion, of corruption. On the other hand, in a few cases, governments are being reluctantly forced to consider relocating cities due to the shortage of freshwater for their growing populations and increasing damage to their infrastructure. But the old city remains occupied, still requiring freshwater, and may still be sinking.

Some governments are proposing desalination of seawater, but these plants are very expensive to construct and to operate. For example, in 2007 during a severe drought, the South Australian state government decided to build a desalination plant to guarantee the water supply to its state capital city, Adelaide, which has a population of ~1.3 million. A desalination plant with the capacity to provide the city with up to fifty per cent of its drinking water needs, around 1,000 gigalitres per year, was completed in 2012 at a cost of A$1.83 billion. It operated at full capacity for two years at a cost of A$130 million per year. After the drought broke in 2015, the plant has been operating at ten per cent of its capacity to reduce costs (DEW, 2022), showing that even an advanced economy has problems affording the construction and operation of a relatively small desalination plant.

With climate change, many regions of the world will experience more droughts, while, combined with population growth, the ability of local storage infrastructure such as dams and aquifers to buffer the population from the impact of such droughts decreases. As water consumption is increasing, water management becomes a major challenge for governments to provide freshwater at minimal cost and minimal energy consumption in a sustainable way, but is made difficult due to the uncertainties created with climate change, growing populations and ageing infrastructure for water supply requiring maintenance or replacement. (Lezcano et al., 2021). Notwithstanding the hyperbole of some billionaire entrepreneurs, the mining of off-the-Earth bodies, such as asteroids and moons, is unlikely to be financially viable nor is there likely to be any benefit to large-scale environmental, social or economic conditions on Earth (Glester, 2018; Zeisl, 2019).

Subsidence is a growing problem in the developing world as cities increase in population and in water use per capita without adequate pumping regulations and/or enforcement (and with possible corruption). Subsidence is not restricted to urban areas but civil infrastructure is more concentrated there, causing a greater amount of damage.

Global drying

The loss of fresh groundwater adds to the loss of fresh surface water, including polar and mountain ice and snow, receding glaciers and the drying and pollution of freshwater rivers and lakes, producing global drying (Diamond, 2011). The increased extraction of groundwater is probably the reason behind the ongoing rise in water use (Steffen et al., 2015). The loss of surface water will decrease the average albedo of the Earth and cause the exposed ground to absorb more of the Sun's radiation contributing to global warming. There is also a consensus among weather modellers that 'the average global biophysical climate response to complete global deforestation is atmospheric cooling and drying' (Perugini et al., 2017: 1). At the 2018 UNESCO World Water Forum held in Brasilia, it was noted that there are a growing number of cities with freshwater shortages. By 2050, five billion people could have poor access to water. It was forecast that by 2025 the global demand for agriculture will increase by sixty per cent with the water required for this. Agriculture is the dominant water user accounting for seventy per cent of global water use and greater than ninety per cent in arid and semiarid regions. Agricultural water use is very inefficient and often, depending on the watering technique employed, only between ten and twenty per cent of the water supplied is utilised by the plants (Lall et al., 2008). A 2018 report (UNWWDR, 2018) states that 'The global demand for water has been increasing at a rate of ~1%/yr over the past decades as a function of population growth, economic development and changing consumption patterns, and it will continue to grow significantly over the foreseeable future.' It recommends using natural processes to improve water availability, such as soil moisture retention, groundwater recharge, improving water quality, and reducing risks associated with water-related disasters and climate change. Other sources of freshwater, such as desalination, recycling, harvesting fog and collecting icebergs from the polar regions, should be developed (Lisbona, 2021). More efficient methods of freshwater use in agriculture and industry should be adopted, as should sewerage treatment to reclaim water, as well as reducing domestic use of water with water tariffs to provide an incentive to save water. However, the 2018 report has been severely criticised for underplaying the connection between population and economic growth, and water demand (Boretti and Rosa, 2019). The UN, through the IAEA, also mediates the water allocations of users of large multinational aquifers, such as the Nubian aquifer in Northern Africa and the Guarani aquifer in South America, in an attempt to avoid conflicts and to sustainably manage the aquifers (Britain et al., 2015). As aforementioned, there have already been conflicts over access to freshwater and other resources, and more are expected to occur (Nnoko-Mewana, 2018; Ribeiro, 2018; Darling, 2019; Angelakis et al., 2021).

A less commonly known effect of global drying is that it changes the distribution of water stored around the Earth (through glacial ice melting and aquifer depletions), which, in turn, contributes to polar drift (Deng et al., 2021). The points where the Earth's rotational axis passes through the Earth's surface, the north and south poles, are not static but move, as does the equator, changing the global weather distribution pattern. Earth's natural climate change is not unexpected: astronomical factors, such as variations in orbital eccentricity, axial tilt, precession of the Earth's orbit and varying luminosity of the Sun, can change, affecting the Earth's weather patterns. For example, at the end of the last Ice Age the Sahara

Desert in northern Africa was as dry and uninviting as it is today. However, ~11,000 BP, arguably the largest climate change-induced environmental change in the Holocene period occurred, rapidly transforming the Sahara into a lush green savannah in less than 500 years, with forests in the valleys, with groundwater sources, that were occupied by prehistoric humans (Cheddudi, 2021). This transformation was caused by slight cyclic changes in the tilt of the Earth's orbital axis, which in turn caused the intensification and northward expansion of the summer monsoon over northern Africa. During a few millennia of plentiful rain and lush vegetation, and under growing population pressures, prehistoric humans evolved from hunter-gathers to farmers with well-established settlements. However, the Green Sahara did not last; the Earth's orbital precession slowly changed again, this time weakening and causing a slow southward contraction of the summer monsoon between 8,200 and 4,500 BP, with a relatively abrupt change ~5,000 BP (Wright, 2017). It is theorised that this contraction was aided by the pastoralists overgrazing and employing fire suppression, which changed the savanna to shrubland, reducing atmospheric moisture and decreasing soil fertility (Boissoneault, 2017). This change in climate was a major factor in the rapid collapse of the Old Kingdom in Egypt ~4,200 BP (Welc and Marks, 2014). A prosperous civilisation which existed for almost 500 years disintegrated in only a couple of decades because of extensive severe drought, catastrophic low floods of the Nile, continual crop failures and mass starvation.

Population growth

The increasing scarcity of freshwater is a critical issue for humanity, with the increasing global population being a significant driver (Ripple et al., 2017; Crist et al., 2022). At the same time, the per capita use of water is increasing as people move from rural to urban areas and from developing to developed countries, particularly as the global middle class grows (Steffen et al., 2015). The availability of freshwater at the local levels must be managed sustainably. Water is a limited resource: however, recycling wastewater and sewerage, desalination and removal of other pollutants requires further limited resources, including energy, which are expensive. Continuing population growth and climate change make the problem more difficult to deal with.

Difficulties in making predictions of future populations – global or urban – create considerable uncertainty in the predicted estimates. Many researchers have attempted to estimate the maximum human carrying capacity (or, more recently, the tipping point population) of the world for a sustainable future. The 65 estimates before 2012, using different models and assumptions, ranged widely from as low as 500 million up to the most common estimate of 8 billion, a number we have recently exceeded (Pengra, 2012). In 2017, the UN Population Division undertook a meta-study of past population estimates (UNDESA, 2017) and concluded that 'it is most likely that the global population will reach 9.8 billion in 2050 and 11.2 billion in 2100'. However, UN Reports in the past have not been reliable (Holm, 2000) and UN development targets not always achieved (Bradshaw et al., 2021), creating some uncertainty in the predicted populations (Pengra, 2012). O'Sullivan (2016) is particularly critical of the UN's population growth projections. Nonetheless, these diverse studies have produced some optimism that all is well (Economist, 2019; Hance, 2020). The question remains: can a good life be provided to all within regional water boundaries if they are better managed?

Considerable faith has been put in the demographic transition occurring to 'bend the population curve' as has already happened in many countries. However, it is not guaranteed to occur in all countries (see Pell, 2016 for a counter example; and Cleland, 2017 for the uncertainty of the sub-Saharan African demographic transition) and, even if it should occur, there is no guarantee that population growth will not restart at some future time, creating further uncertainty for urban planners. An unexpected situation that is currently occurring is due to many nations adopting de facto open national borders, allowing apparently organised mass migrations from the developing to the developed nations, so leading to an increase in unplanned urbanisation and chaos in many of the developed countries.

Conclusion

There are challenges in improving the global water cycle (Lall et al., 2008) and individual urban water cycles (Lezcano et al., 2021) by sustainable means, which are made more difficult with growing populations. As discussed above, urban water cycles are different in each city, depending upon local geography, demographics and weather patterns, which will change with global warming. Past civilisations on Earth collapsed because the leaders were not sufficiently knowledgeable or forward thinking (Diamond, 2011; Ialenti, 2020), which still appears to be a problem in many countries. Unfortunately, it is easier to see the collapse of civilisations in hindsight and being on the outside rather than on the inside (Power, 2000). Groundwater is a particular problem due to its invisibility to managers and ease of access by users. At the local level, there must be improvements in the use of water as outlined by the UN, including being better management and stricter regulation. Importantly, urban design must allow any underlying aquifers to be recharged to avoid infrastructure damage. It has been argued that there are uncertainties with attempting to estimate future populations, both globally and in urban settings, and with whether the demographic transition will necessarily occur and persist.

A solution to the increasing global population, which is driving global drying, amongst other environmental problems, is not impossible (Pengra, 2012; Perkins, 2017; Tucker, 2020). Particular attention must be paid to the effect of rising populations (including through migrations) on local water resources, especially groundwater, and the knock-on effect on urban sustainability. As aforementioned, water stress has frequently been linked with social tension and conflict, which should be avoided in any urban planning.

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PEER REVIEWED ARTICLE

A comparison of mortality transition in China and India, 1950–2021

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Abstract

This paper compares mortality transition in China and India in the period 1950–2021, highlighting similarities and differences. Mortality transition has been inconsistent in both countries, but differences remain. In China, the transition has been spread evenly across the age range, while in India, it has primarily been confined to younger ages, being markedly slow in ages 35–90. This difference in the older ages appears to explain the main difference between the respective mortality transition in the two countries. To address its ongoing mortality transition, the paper concludes, India needs to reinvigorate its health-care delivery system to meet the health care needs of the old people. The paper also emphasises using geometric mean of the age-specific probabilities of death as an appropriate measure to analyse mortality transition.

Keywords: mortality transition, China, India, geometric mean, life expectancy, decomposition.

Introduction

China and India are the only billion-plus countries in the world and, together, they accounted for almost 36 per cent of the world's population in 2021 (United Nations, 2022). The world's demographic prospects have therefore been, and

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continue to be, closely linked to the demographic transition of both countries. The comparative demography and development has in both cases always been of interest to both demographers and development experts (Coale, 1983; Adlakha and Banister, 1995; Dummer and Cook, 2008; Singh and Liu, 2012; Golley and Tyres, 2013; Joe et al, 2015; Chaurasia, 2017; 2020). While around 1950, China and India were at a very similar stage of demography and development, the situation has now changed radically. China is now at a very advanced stage of demographic transition and its population has just started to decline. In contrast, India continues to be in the middle of a transition, although it has recently achieved replacement fertility. The population of India continues to increase, albeit at a slower pace, and its population now appears to have surpassed that of China.

Socially, culturally and politically, China and India are poles apart. This has implications for both the population and the development processes in the two countries. In China, the Han ethnic community constitutes more than 90 per cent of the population (Chen et al., 2009). China is also one of the few countries of the world that has never been entirely colonised by foreign powers, with the result that its society, culture and economy – especially of the mainland – has remained largely unaffected by colonisation. After becoming communist in 1948, the country adopted a single-party political system which has left virtually no scope for democratic influence on government policies and programmes with implications for demography and development.

The social, cultural and political diversity of India, on the other hand, is so great that India is often called 'the country of countries'. Its society and culture are both deeply complex and fragmented, and one reason is the rule by foreign invaders that lasted for almost 1,000 years. Indian society is broadly divided into two classes – the rulers and the ruled – and there is a great divide between the two. After independence in 1947, India adopted a multi-party political system which has led to a democratic diversity of the extreme order. One implication of this political system is that there has rarely been political consensus on key issues related to demography and development. This lack of political consensus has influenced India's demographic processes as well as its social and economic development.

It is against the above background that this paper analyses the mortality transition in China and India in 1950–2021 through a comparative perspective.

This comparison is important since mortality transition signals the beginning of demographic transition. Falling mortality has also been suggested as an indicator of economic success. Moreover, transition in mortality can also throw light on the transition in social and economic development processes in terms of social inequalities, including gender and racial disparities (Sen, 1998). Understanding mortality transition is therefore the first step towards understanding demographic transition and towards characterising social and economic development processes. The analysis in this paper shows that China's mortality transition has been different from that in India during the investigated period. The analysis also shows that mortality transition described by the time trend in different measures of aggregate mortality are essentially different.

Mortality transition encompasses a decrease in aggregate mortality level and change in the age pattern of mortality. The most commonly used measure of analysing mortality transition at the aggregate level is the life expectancy at birth (e_0), which is independent of population age structure so that it can be compared over time and across different populations at different stages of mortality transition. However, e_0 reflects mortality experience of a hypothetical population and not of the real population. It is the average of the age distribution of deaths and is therefore not unique. Different age distributions of deaths may have the same e_0 (Goerlich Gisbert, 2020). The increase in e_0 is also influenced more by the decrease in the risk of death at older ages than the decrease in the risk of death at younger ages (Chaurasia, 2023; Keyfitz, 1977; Vaupel, 1986).

In view of the limitations of e_0, alternative measures of aggregate mortality have been suggested. One alternative is the median age at death (INE, 1952, 1958) while the other is the modal age at death (Canudas-Romo, 2008). The geometric mean of age-specific death rates (Schoen, 1970) and geometric mean of age distribution of deaths (Ghislandi et al., 2019) have also been suggested. Goerlich Gisbert (2020) has suggested a distributionally adjusted e_0 that considers not only the level but also the age distribution of deaths. Chaurasia (2023) has used the geometric mean of the age-specific probabilities of death as the measure of aggregate level of mortality to analyse mortality transition in India. The advantage of using the probability of death rather than death rate is the ease in the interpretation of the probability of death, since the conditional probability of death is defined as the number of deaths over the course of a given time period and in an age cohort divided by the living population at the start of the time period (King and Soneji, 2011). The probability of death always ranges between 0 and 1 and is used for the construction of the life table and calculation of e_0 (de Beer 2012).

The paper is organised as follows. The next section of the paper describes the data source and analytical methods used in the paper. The third section analyses mortality transition in China and India between 1950 and 2021, in terms of the time trend in the two measures of aggregate mortality – the life expectancy at birth (e_0) and the geometric mean of the age-specific probabilities of death. The fourth section of the paper analyses how changes in the age-specific probabilities of death contribute to the change in the geometric mean of age-specific probabilities of death. The fifth section analyses the transition in age-specific probabilities of death in the two countries by fitting a non-parametric model. The sixth section decomposes the difference in the age-specific probabilities of death between the two countries into four components, the difference in average probability of death across all years and all ages, difference in average probability of death across all ages in different years, difference in average probability of death across years in different ages and difference in a residual component that is not explained by the first three components. The last section of the paper summarises main findings of the analysis that characterise the difference in mortality transition between China and India since 1950.

Data and methods

This paper is based on the United Nations Population Division's (UNPD) estimates of the age-specific probabilities of death by single years of age for the period 1950–2021, part of its 2022 revision of the world population prospects (United Nations, 2022). These estimates are based on a uniform methodology and a standard set of assumptions for all countries and they therefore permit inter-country comparison. This may not be the case with the official estimates, as the official estimates of different countries may be based on different methodologies and different sets of assumptions. The difference between the United Nations' estimates and the official estimates of the age-specific probabilities of death is, however, small in both China and India.

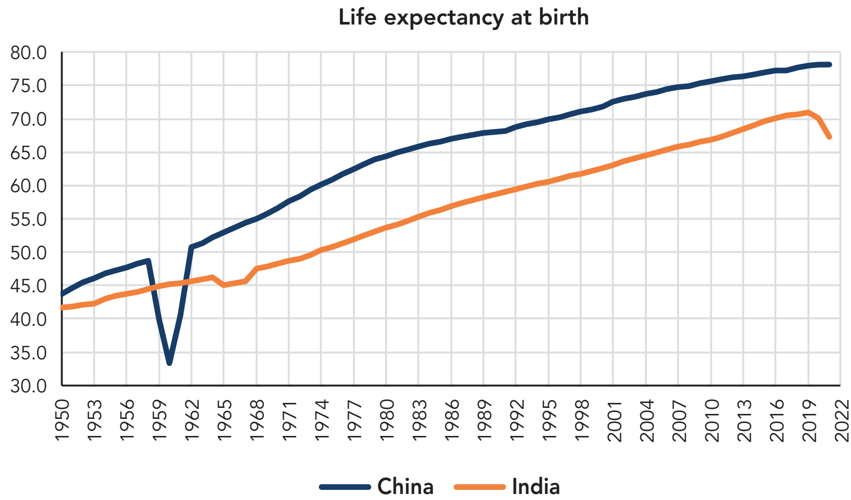
The methods used for analysing transition in mortality in the two countries involve analysis of the time trend and the decomposition analysis. The appendix to the paper describes, in detail, the approach adopted for the analysis of the time trend and the method of decomposition. The analysis of the time trend is based on the underlying assumption that the trend may be different in different time-segments of the trend period 1950–2021. On the other hand, the change in the aggregate measure of mortality has been decomposed into the change in different components of the aggregate measure to understand the determinants of change.

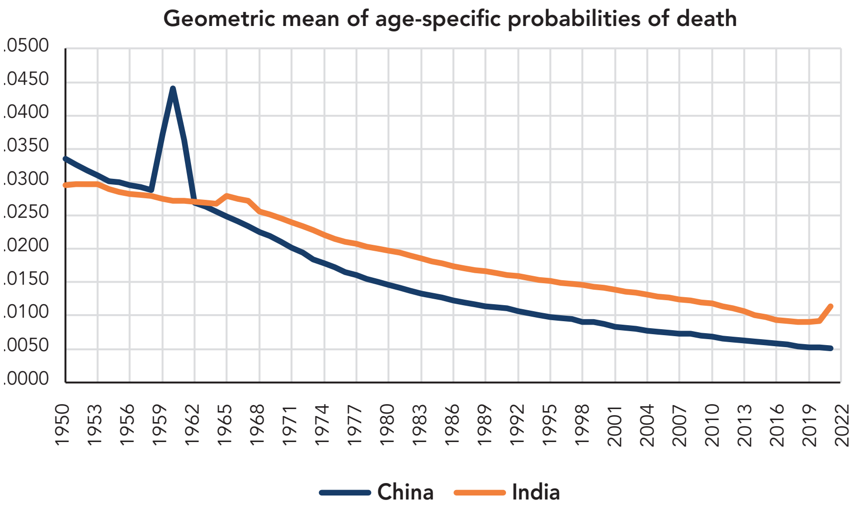
Trend in aggregate measures of mortality

Estimates prepared by the United Nations suggest that life expectancy at birth (e_0) in China increased from around 43.7 years in 1950 to more than 78 years in 2021 (United Nations, 2022), an increase of more than 34 years between 1950 and 2021 (Figure 1). In India, e_0 increased by around 25 years during this period, from 41.7 years in 1950 to 70.9 years in 2019, but then decreased to 67.2 years in 2021 possibly because of the mortality impact of COVID-19 pandemic. Similarly, the geometric mean of age-specific probabilities of death decreased from 0.0234 in 1950 to 0.0048 in 2021 in China, whereas in India, it decreased from 0.0286 in 1950 to 0.0086 in 2019 and then increased to 0.0109 in 2021. In China, e_0 increased while the geometric mean of age-specific probabilities of death decreased even during the COVID-19 pandemic. In contrast, e_0 in India decreased, while the geometric mean of age-specific probabilities of death increased during the pandemic. Overall, the geometric mean of age-specific probabilities of death was lower in India than in China in the period 1950–1961 while, except the short period between 1959 and 1961, China's e_0 has always been higher than that of India.

Figure 1 also suggests that, in both countries, the trend in e_0 and in the geometric mean of the age-specific probabilities of death changed many times between 1950 and 2021. I have, therefore, analysed the trend using the joinpoint regression model, which first identifies inflexion point(s) in the trend and then estimates the trend between two successive inflexion points assuming a linear trend. If there is no point of inflexion, the joinpoint regression model reduces to a simple linear model. I have used the Joinpoint Regression Program software (National Cancer Institute, 2023) for this purpose. The software requires, a priori, minimum and maximum number of joinpoints. When the number of joinpoints is zero, the software fits a straight line. The software provides estimates of annual per cent change (APC) in different time-segments of the trend period. The APCs in different time-segments may be combined into average annual per cent change (AAPC) during the trend period as the weighted average of APC in different time-segments with weights equal the length of the time-segment. The AAPC gives

Figure 1: Trend in summary measures of mortality in China and India, 1950–2021





SOURCE: AUTHOR

a better reflection of the trend over time compared to the conventional rate of change obtained through the application of the linear regression analysis on a logarithmic scale (Clegg et al., 2009).

Table 1 presents results of the joinpoint regression analysis. In China, the trend in e_0 changed four times between 1950 and 2021 and the trend has been different in different time-segments. Combining the APC in different time-segments, the average annual per cent change (AAPC) in e_0 in China was 0.849 per cent per year in 1950–2021 with the rate of increase slowing down considerably after 1981. In India, the trend in e_0 changed five times. In 1963–1966, e_0 in the country remained virtually stagnant. The rate of improvement in e_0 in India was slower than that in China before 1986, but faster than China between 1986 and 2019. The gap in e_0 between the two countries, therefore, first increased and then decreased to the lowest since 1965 in 2017. After 2017, the gap increased again and, during the COVID-19 pandemic (2020–2021), e_0 in India decreased very rapidly leading to a very rapid increase in the gap. The AAPC in e_0 in India during 1950 and 2021 has also been much slower than that in China.

Table 1. Analysis of the trend in e_0 in China and India, 1950–2021

Segment	Time-segment		Annual per cent change			Test statistic (t)	Prob > |t|
	Lower	Upper	Estimate	Lower CI	Upper CI		
	China						
1	1950	1957	1.909	1.706	2.112	18.986	< 0.001
2	1957	1960	-10.563	-12.032	-9.069	-13.491	< 0.001
3	1960	1963	13.650	11.783	15.548	15.462	< 0.001
4	1963	1981	1.261	1.209	1.313	49.180	< 0.001
5	1981	2021	0.484	0.470	0.498	69.032	< 0.001
Full Range	1950	2021	0.849	0.748	0.949	16.575	< 0.001
	India						
1	1950	1963	0.827	0.794	0.861	49.811	< 0.001
2	1963	1966	-0.801	-1.573	-0.022	-2.060	0.044

Segment	Time-segment		Annual per cent change			Test statistic (t)	Prob > |t|
	Lower	Upper	Estimate	Lower CI	Upper CI		
3	1966	1969	1.921	1.127	2.721	4.875	< 0.001
4	1969	1986	1.047	1.023	1.071	86.807	< 0.001
5	1986	2019	0.683	0.674	0.691	162.607	< 0.001
6	2019	2021	-2.639	-3.405	-1.867	-6.786	< 0.001
Full Range	1950	2021	0.690	0.638	0.742	26.203	< 0.001

SOURCE: AUTHOR

The trend in the geometric mean of the age-specific probabilities of death, on the other hand, changed five times in both countries during the period 1950–2021 (Table 2). The points of inflexion in the trend in the geometric mean of age-specific probabilities of death have been the same as e_0 during 1950–1963 in China and during 1950–1966 in India. However, after 1963 in China and after 1966 in India, the points of inflexion in the trend in the geometric mean of the age-specific probabilities of death have been different from the points of inflexions in the trend in e_0. A comparison of tables 1 and 2 suggests that the mortality transition reflected by the trend in e_0 is different from the mortality transition reflected by the trend in geometric mean of age-specific probabilities of death in both countries. One reason for this difference is that the trend in e_0 depicts mortality transition in a hypothetical population, whereas the trend in geometric mean of age-specific probabilities of death depicts mortality transition in the real population. A comparison of period age-specific probabilities of death in 1950 with those for the cohort born in 1950 for ages 0–71 years reveals that the two sets of age-specific probabilities of death are different in both countries. For example, a person born in 1950 in China was 71 years old in 2021 and the probability of death for the person in the 71st year of life was 0.0241, whereas the probability of death in 71 years of age in 1950 was 0.0945. The e_0 for the year 1950 is calculated assuming that a person born in 1950 will be subject to age-specific probabilities of death that prevailed in the year 1950. However, the actual age-specific probabilities of death to which a person born in 1950 was subjected to the 1950 cohort age-specific probabilities of death were substantially lower than the age-specific probabilities that prevailed in 1950. Obviously, the actual age-specific risk of death experienced by a person born in 1950 is different from the age-specific risk of death reflected by the age-specific probabilities of death that prevailed in the country in 1950. In India also, the risk of death experienced by a person born in 1950 in the 71st year of life was different from the probability of death in 71 years of age in the year 1950, although the difference between the cohort and the period age-specific probabilities of death in India is relatively narrower than that in China.

The difference in the trend in e_0 and the trend in the geometric mean of the age-specific probabilities of death suggests that it is more appropriate to use the geometric mean of the age-specific probabilities of death as the summary measure of mortality than the life expectancy at birth. The use of geometric mean of age-specific probabilities of death as the summary measure of mortality has many advantages. The geometric mean gives equal weight to probabilities of death in different ages. This is not the case with e_0. The change in any of the age-specific probabilities of death results in a change in the geometric mean of the age-specific probabilities of death, which is not the case with the median or the mode of the age-specific probabilities of death. The geometric mean also addresses the problem of perfect substitutability associated with arithmetic mean.

Table 2: Analysis of the trend in the geometric mean of age-specific probabilities of death (*g*) in China and India, 1950–2021

Segment	Time-segment		Annual per cent change			Test statistic (t)	Prob > |t|
	Lower	Upper	Estimate	Lower CI	Upper CI		
	China						
1	1950	1957	-2.494	-2.814	-2.172	-15.388	< 0.001
2	1957	1960	14.364	11.010	17.819	9.036	< 0.001
3	1960	1963	-15.646	-18.120	-13.097	-11.455	< 0.001
4	1963	1966	-1.100	-4.000	1.889	-0.744	0.460
5	1966	1979	-3.753	-3.889	-3.618	-54.330	< 0.001
6	1979	2021	-2.516	-2.536	-2.496	-243.490	< 0.001
Full Range	1950	2021	-2.620	-2.832	-2.409	-23.959	< 0.001

Segment	Time-segment		Annual per cent change			Test statistic (t)	Prob > |t|
	Lower	Upper	Estimate	Lower CI	Upper CI		
	India						
1	1950	1963	-0.873	-1.005	-0.740	-13.161	< 0.001
2	1963	1966	1.035	-1.741	3.890	0.741	0.462
3	1966	1976	-2.741	-2.968	-2.513	-23.807	< 0.001
4	1976	2009	-1.650	-1.683	-1.616	-97.609	< 0.001
5	2009	2019	-3.269	-3.495	-3.043	-28.475	< 0.001
6	2019	2021	12.909	9.802	16.103	8.720	< 0.001
Full Range	1950	2021	-1.398	-1.544	-1.251	-18.578	< 0.001

SOURCE: AUTHOR

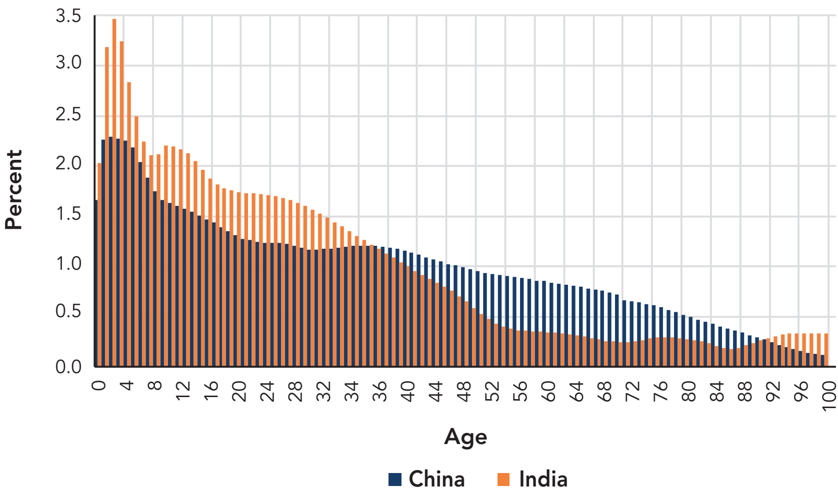
I have used the age-specific probabilities of death, instead of the age-specific death rates, to analyse mortality transition by age. The reason is that the probability of death in the last, open-ended age interval is always equal to 1 so that the geometric mean of the age-specific probabilities of death is not influenced by the risk or the probability of death in the last, open-ended age interval. This is not the case with the death rate and the difficulty in estimating the death rate in the last, open-ended age interval is well-known. The death rate in the last, open-ended age interval is always an approximation. It is also straightforward to decompose the change in the geometric mean of the age-specific probabilities of death to the change in the probability of death in different ages. This decomposition helps in characterising and comparing mortality transition.

Decomposition of the change in g

I have used index decomposition analysis (IDA) approach to decompose the change in the geometric mean of age-specific probabilities of death (*g*) over time into the change in the age-specific probabilities of death. The IDA approach was first used in the early 1980s to decompose the change in the industrial energy consumption and has since been widely applied in energy and emission studies (Ang, 2015). Among different IDA approaches, the Logarithmic Mean Divisia Index (LMDI) approach is the most popular (Ang, 2005; Ang and Liu, 2001) because of many desirable properties it possesses (Ang, 2004). The approach has been used in analysing the contribution of different factors to the increase in energy consumption and Carbon Dioxide emission (Makutėnienė et al, 2022; Lisaba and Lopez, 2020; He and Myers, 2021; Tu et al., 2019). It has also been used in analysing how the change in different factors contribute to the change in demographic indicators (Chaurasia, 2023). The details of the LMDI approach of decomposition are given in the appendix.

Results of the decomposition analysis are presented in Figure 2 and summarised in Table 3. More than 53 per cent of the decrease in *g* in China during 1950–2021 is attributed to the decrease in the probability of death in the population younger than 35 years of age, whereas this proportion is almost 70 per cent in India. The decrease in the probability of death in the population aged 35–90 accounts for a decrease of almost 45 per cent in *g* in China but less than 28 per cent in India. The contribution of the decrease in the probability of death in the age group 55–90 years was less than 10 per cent in India but more than 23 per cent in China. In both countries, decrease in the probability of death in the age group 1–14 years accounted for most of the decrease in *g* – around 24 per cent in China but almost 31 per cent in India.

Figure 2: Proportionate contribution of the decrease in the probability of death in different ages to the decrease in *g* in China and India, 1950–2021



SOURCE: AUTHOR

Table 3. Contribution of the change in probability of death in different age-groups to the change in the geometric mean of the age-specific probabilities of death (*g*) in China and India, 1950–2021

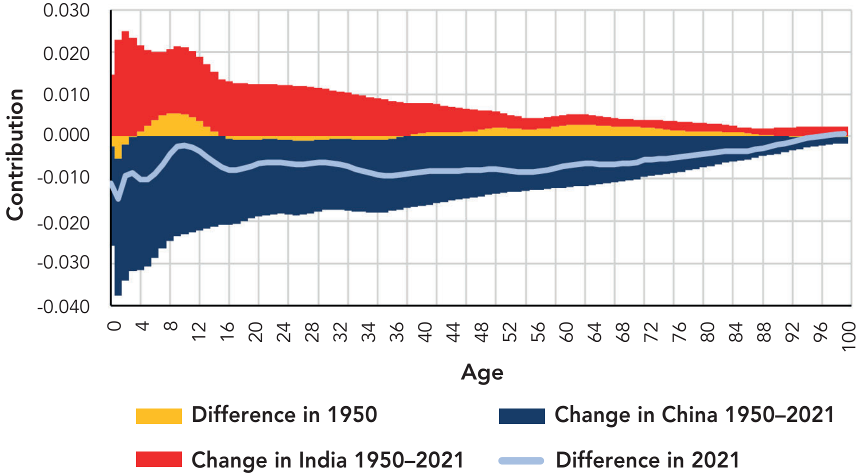
Age	China						
	Change in *g* during the period						
	1950–2021	1950–1957	1957–1960	1960–1963	1963–1966	1966–1979	1979–2021
	-0.0127	-0.0042	0.0145	-0.0172	-0.0022	-0.0088	-0.0096
	Contribution of the change in the probability of death in the age group						
0	1.65	1.16	-1.36	1.36	1.05	1.25	1.96
1–4	9.02	7.69	-8.88	8.87	6.71	7.99	9.84
5–9	9.47	9.86	-9.97	9.98	6.94	7.83	10.30
10–14	7.87	10.74	-9.57	9.57	6.34	5.95	8.30
15–19	6.98	9.76	-6.85	7.48	6.92	5.85	6.84
20–24	6.28	8.56	-5.78	6.53	7.57	6.14	5.64
25–29	6.06	8.68	-5.64	6.07	6.96	6.69	5.21
30–34	5.95	9.34	-5.81	6.12	6.07	6.41	5.17
35–39	6.05	8.40	-5.71	6.26	5.95	6.08	5.52
40–44	5.78	6.96	-5.09	5.65	6.87	5.58	5.43
45–49	5.25	5.85	-5.09	5.31	6.49	5.60	4.83
50–54	4.80	5.55	-4.65	4.67	5.55	5.60	4.29
55–59	4.48	5.87	-4.65	4.52	4.85	5.13	4.04
60–64	4.21	4.56	-3.79	3.96	4.38	4.37	4.04
65–69	3.90	3.28	-3.64	3.64	4.92	3.81	3.96
70–74	3.41	1.72	-3.46	3.23	4.12	3.68	3.55
75–79	2.93	1.47	-3.43	2.84	3.37	3.55	3.04
80–94	2.33	-0.33	-2.30	1.87	2.06	3.11	2.56
85–89	1.77	-1.57	-1.85	1.21	2.08	2.34	2.21
90–94	1.17	-3.33	-1.42	0.57	0.86	1.81	1.87
95–99	0.67	-4.22	-1.05	0.32	-0.05	1.22	1.42

	India						
	Change in *g* during the period						
	1950–2021	1950–1963	1963–1966	1966–1976	1976–2009	2009–2019	2019–2021
	-0.0177	-0.0026	0.0006	-0.0063	-0.0088	-0.0029	0.0023
	Contribution of the change in the probability of death in the age group						
0	2.03	1.77	-0.55	0.70	1.75	1.81	0.38
1–4	12.72	11.45	-8.41	4.33	11.36	11.17	2.13
5–9	11.18	7.02	-30.79	2.14	11.11	11.98	1.99
10–14	10.49	7.31	-16.48	7.41	9.60	7.31	1.00
15–19	8.96	5.45	3.16	6.23	8.27	8.11	-2.95
20–24	8.58	5.45	4.83	6.04	7.63	8.99	-4.02
25–29	8.14	5.47	5.22	7.24	7.50	6.58	-3.93
30–34	7.19	5.77	3.17	8.21	6.28	5.60	-4.66
35–39	6.08	5.77	2.28	8.01	5.80	3.61	-5.28
40–44	4.99	5.51	-0.08	6.49	5.99	1.70	-5.75
45–49	3.96	5.42	-3.82	4.95	4.68	3.56	-6.91
50–54	2.67	5.35	-6.51	3.43	4.81	1.02	-7.31
55–59	1.84	5.21	-7.95	2.18	4.81	-0.54	-7.14
60–64	1.69	4.96	-8.88	1.55	3.74	2.48	-8.03
65–69	1.43	4.58	-9.08	2.17	2.74	3.01	-7.89
70–74	1.26	4.07	-8.75	2.92	1.96	3.16	-7.56
75–79	1.43	3.37	-7.11	3.46	1.96	2.90	-7.03
80–94	1.24	2.58	-4.33	4.44	0.95	4.05	-7.91
85–89	0.99	1.84	-2.97	5.37	0.19	4.55	-8.61
90–94	1.49	1.04	-1.76	6.34	-0.35	4.53	-6.19
95–99	1.64	0.62	-1.20	6.37	-0.76	4.41	-4.33

SOURCE: AUTHOR

Table 3 also decomposes the decrease in *g* in different time-segments in which the trend in *g* has been different. In China, the probability of death in the population aged at least 80 years increased during 1950–1957 and therefore contributed to increase, instead of decrease, in *g*. During 1957–1960, increase in the probability of death in all ages contributed to an increase in *g* in China and, after 1960, the decrease in the probability of death in all ages contributed to the decrease in *g* with the only exception of the population aged at least 90 years during 1963–1966. In India, decrease in *g* during 1950–1963 was due to a decrease in the probability of death in all ages whereas the increase in *g* during 1963–1966 was due to the increase in the probability of death in the population below 15 years of age and in the population aged at least 40 years. During 1966–2019, the decrease in the probability of death in all ages contributed to the decrease in *g* in India except during 1966–2019. During the COVID-19 pandemic, *g* increased, and this increase was due to the increase in probability of death in ages 15 years and above.

Figure 3: Decomposition of the difference in *g* in China and India in 2021



SOURCE: AUTHOR

The difference in *g* between the two countries at time $t_2 > t_1$ depends upon three factors: the difference in *g* between two populations at time t_1 and the change in *g* in the two countries between t_1 and t_2 (Andreev et al., 2002; Jdanov et al., 2017). The LMDI approach can also be used to carry out this decomposition. The details are given in the appendix and the decomposition results are presented in Figure 3. In 1950, *g* was higher in China because of higher probability of death in ages 3–15 and 40–91. The decrease in the probability of death in ages below 96 years has been more rapid in China but, in ages 96 and above, more rapid in India. The contribution of the decrease in the probability of death in ages 0–37 and in ages 91 and above to the decrease in *g* has been higher in India, but, in ages 38–90, it has been higher in China. The lower mortality in China in 2021 has been due to a relatively more rapid decrease in the probability of death in ages 0–95. However, the decrease in the probability of death in ages 96 and above has been more rapid in India, which has contributed to narrowing down the difference in mortality between China and India in 2021.

Modelling age-specific probability of death

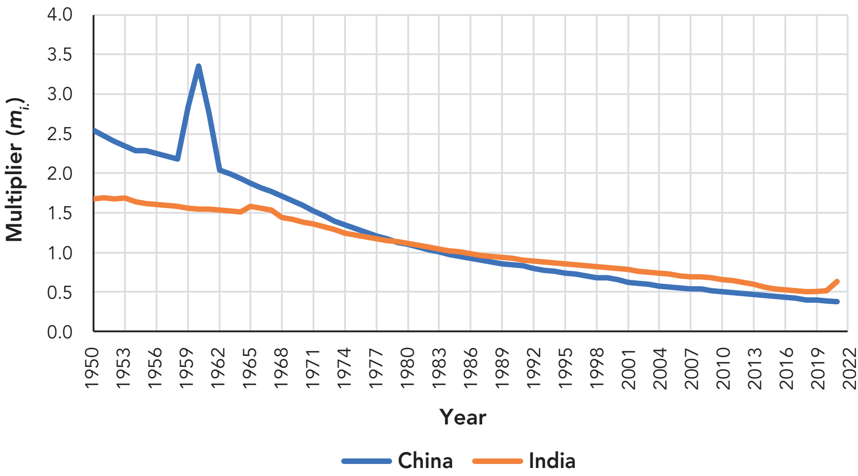
The age-specific probability of death in year *i* and age *j*, q_{ij} can be modelled in terms of: a common factor ($q_{..}$) across all *i* and *j*; a row factor or factor specific to the year ($q_{i.}$), which is common to all columns or ages *j* of the row or the year *i*; a column factor or factor specific to age ($q_{.j}$) which is common to all rows or years *i* of the column or age *j* and a residual factor r_{ij}, which is specific to each pair of *i* and *j* as shown in the appendix. This model can be fitted through the polishing technique, first proposed by Tukey (1977), by choosing an appropriate polishing function. The technique successively sweeps the polishing function out of rows (divides row values by the polishing function for the row), then sweeps the polishing function out of columns (divides column values by the polishing function for the column), then rows, then columns and so on, and accumulates them in 'all', 'row' and 'column' registers to obtain values of $q_{..}$, $m_{i.}$ and $m_{.j}$ respectively, and leaves behind a table of residuals (m_{ij}) which are specific to year *i* and age *j*. When the entire variation in q_{ij} is explained by $q_{..}$, $m_{i.}$ and $m_{.j}$ or, equivalently, by $q_{..}$, $q_{i.}$ and $q_{.j}$, all m_{ij} are equal to 1. Otherwise m_{ij} reflects that part of q_{ij} that is not explained by $q_{..}$, $m_{i.}$ and $m_{.j}$. The mathematical formulation of the model is given in the appendix.

I have used the geometric mean as the polishing function to model q_{ij}. The use of geometric mean as the polishing function ensures that the geometric mean of residual multipliers m_{ij} is equal to 1; geometric mean of m_i, is equal to 1 and geometric mean of $m_{.j}$ is also equal to 1. It may be noticed that all the three multipliers $m_{i.}$, $m_{.j}$ and m_{ij} can be less than or more than 1. A value of the multiplier greater than 1 inflates $q_{..}$ whereas a value less than 1 deflates $q_{..}$. For example, if $m_{i.}>1$, then $q_{i.}$ is higher than $q_{..}$, but if $m_{i.}<1$, then $q_{i.}$ is lower than $q_{..}$ and $q_{i.}$ is equal to $q_{..}$ if $m_{i.}=1$. Similar interpretation can be made for the multiplier $m_{.j}$. On the other hand, if $m_{ij}>1$ than q_{ij} is higher than that determined by $q_{..}$, $m_{i.}$ and $m_{.j}$. If $m_{ij}<1$ than q_{ij} is lower than that determined by $q_{..}$, $m_{i.}$. When $m_{ij}=1$, q_{ij} is the same as that determined by $q_{..}$, $m_{i.}$ and $m_{.j}$.

For both countries, I have used 7100 q_{ij} values, *i* ranging from 1 (1950) to 71 (2021) and *j* ranging from age 0 to age 99 for modelling the age-specific probabilities of death in terms of the parameters $q_{..}$, $m_{i.}$, $m_{.j}$ and m_{ij}. The $q_{,,}$ for China (0.0127) is estimated to be around 25 per cent lower than the $q_{..}$ for India (0.0170), which indicates that overall mortality level in India has been higher than that in China throughout the period under reference. If the period of the COVID-19 pandemic (2020–2021) is excluded from the modelling exercise, then $q_{..}$ is estimated to be around 32 per cent higher in India (0.0173) than that in China (0.0131). This implies that the COVID-19 pandemic has resulted in widening the difference in overall mortality between the two countries. The impact of the epidemic on mortality has been more in India than in China.

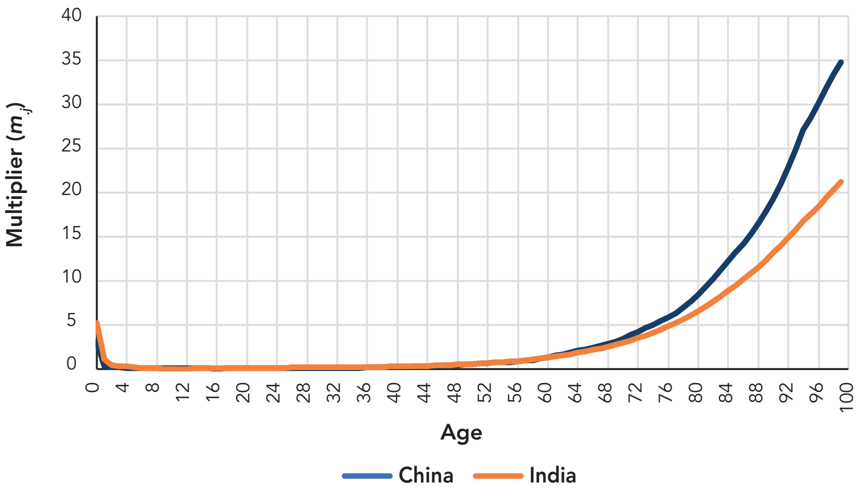
The modelling of the age-specific probabilities of death also reveals that the multiplier $m_{i.}$ has decreased in both countries during the period under reference, although the trend has been different in the two countries (Figure 4a). The joinpoint regression analysis suggests that $m_{i.}$ decreased in China at an average annual rate of decrease of 2.64 per cent per year during 1950–2021, whereas the average annual rate of decrease in India was only 1.41 per cent per year, which indicates that the decrease in the average mortality has been more rapid in China than in India. In China, $m_{i.}$ was greater than 1 up to 1983 but turned less than 1 after 1983. In India, $m_{i.}$ was greater than 1 up to 1985. An $m_{i.}>1$ implies $q_{i.}>q_{..}$. Figure 7 also shows that $m_{i.}$ was higher in China than in India during 1950–1978, but after 1978 it turned higher in India. The age multiplier $m_{.j}$ has also been different in the two countries (Figure 4b). The average probability of death in the first year of life during 1950–2021, $q_{.1}$, was more than 3 times $q_{..}$ in China but more than 5 times in India. However, in ages 8–13, multiplier $m_{.j}$ has been higher in China than in India, suggesting that, relative to $q_{..}$, the probability of death in China was higher than that in India in these ages. Similarly, in ages 60 and above, multiplier $m_{.j}$ was again higher in China than in India and the difference increased with age. The $q_{.90}$ was more than 19 times the $q_{..}$ in China but only about 13 times the $q_{..}$ in India. In ages 9–60, however, $q_{.j}$, relative to $q_{..}$ has been higher in India than in China.

Figure 4a: Trend in $m_{i.}$ in China and India, 1950–2021



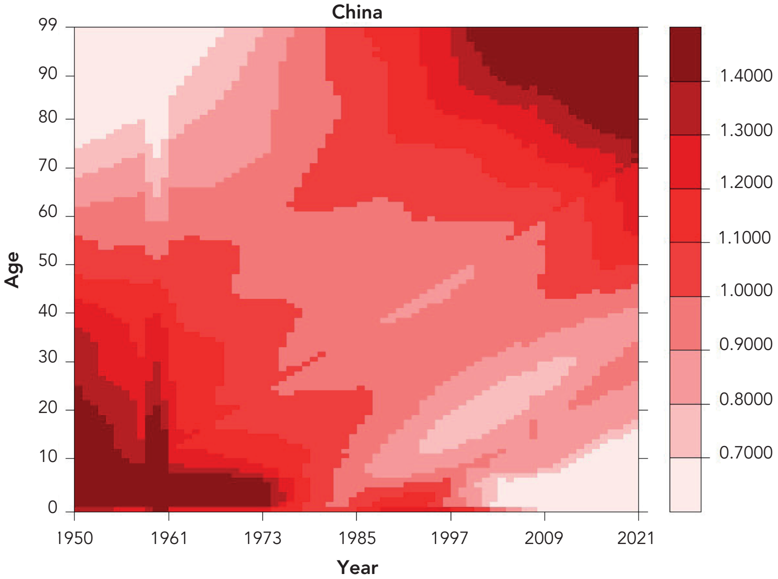
SOURCE: AUTHOR

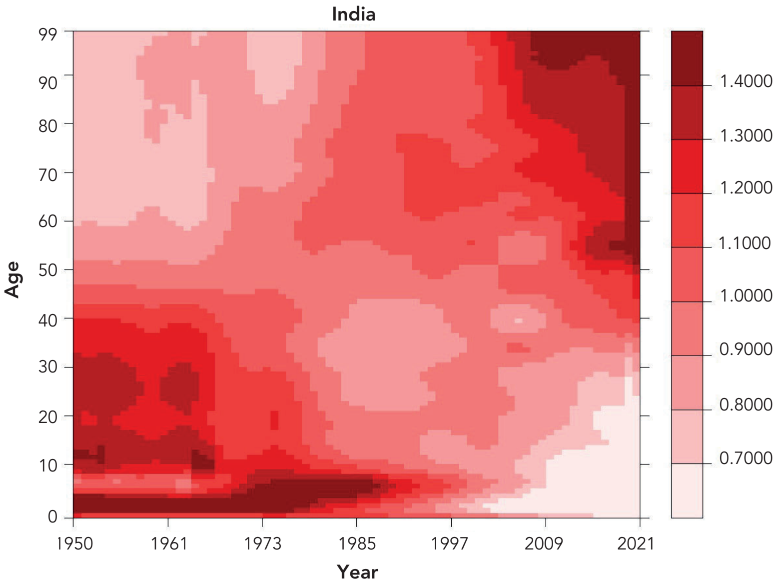
Figure 4b: The age multiplier ($m_{.j}$) common to the period 1950–2021 in China and India



SOURCE: AUTHOR

Figure 5: Residual multipliers (m_{ij}) in China and India





SOURCE: AUTHOR

The trend in m_{ij} in the two countries is depicted in Figure 5. In both countries, m_{ij} decreased markedly with time in younger ages but increased in older ages, whereas the change in the middle ages has not been marked. An increase in m_{ij} implies an increase in actual probability of death specific to the year *i* and age *j* that is not explained by $q_{..}$, $q_{i.}$ and $q_{.j}$ and vice versa. For example, the probability of death in the first year of life in China was more than 30 per cent higher than that explained by $q_{..}$, $m_{i.}$ and $m_{.j}$ in 1950 but more than 62 per cent lower in 2021. The probability of death in the first year of life remained higher than that explained by $q_{..}$, $m_{i.}$ and $m_{.j}$ in China up to 2002. By contrast, actual probability of death in the first year of life in India was around 21 per cent higher than that explained by $q_{..}$, $m_{i.}$ and $m_{.j}$ in 1950 but about 55 per cent lower in 2021. The actual probability of death in the first year of life remained higher than that explained by $q_{..}$, $m_{i.}$ and $m_{.j}$ in India up to 1997. On the other hand, the actual probability of death at 80 years of age in China was around 24 per cent lower than that explained by $q_{..}$, $m_{i.}$ and $m_{.j}$ in 1950 but was more than 59 per cent higher in 2021. Similarly, the actual probability of death at 80 years of age in India was around 38 per cent lower than that explained by $q_{..}$, $m_{i.}$ and $m_{.j}$ in 1950 but was almost 54 per cent higher in 2021. In China, the actual probability of death in the year 1950 was higher than that explained by $q_{..}$, $m_{i.}$ and $m_{.j}$ up to 56 years of age but up to 47 years age in 2021. In India, the actual probability of death in 1950 was higher than that explained by $q_{..}$, $m_{i.}$ and $m_{.j}$ up to 47 years of age but up to 37 years of age in 2021.

Decomposing the change in age-specific probabilities of death

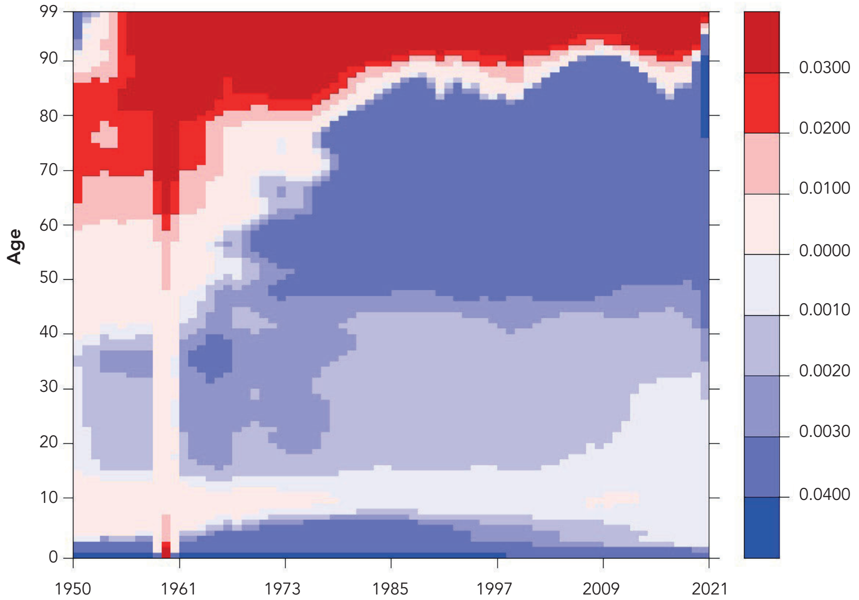
The modelling of q_{ij} in terms of $q_{..}$, $m_{i.}$, $m_{.j}$ and m_{ij} permits decomposing the difference in q_{ij} between China and India in terms of the difference in $q_{..}$, $m_{i.}$, $m_{.j}$ and m_{ij} following the LMDI approach. The decomposition results are presented in Figure 6 for the period 1950–2021 and for ages 0–99. A negative value of the difference means that q_{ij} is higher in India as compared to China. On the other hand, a positive value of the difference means a higher q_{ij} in China than in India. Figure 6 shows that q_{ij} was not always lower in China. The magnitude of the difference varied across ages and over time. In ages 50–90, the probability of death in India has markedly been higher than that in China after 1980, but in ages <5 years and ≥90 years, the probability of death has markedly been higher in China than in India.

Table 4. Decomposition of the difference in q_{ij} between China and India

Measure	1950			1985			2021		
	China	India	Difference/ contribution	China	India	Difference/ contribution	China	India	Difference/ contribution
Age 0 years									
q_{ij}	0.132	0.187	-0.049	0.041	0.102	-0.060	0.006	0.026	-0.020
$q_{..}$	0.013	0.017	-0.045	0.013	0.017	-0.019	0.013	0.017	-0.004
$m_{i.}$	2.545	1.678	0.065	0.952	1.003	-0.004	0.377	0.638	-0.007
$m_{.j}$	3.119	5.230	-0.080	3.119	5.230	-0.035	3.119	5.230	-0.007
m_{ij}	1.304	1.212	0.011	1.087	1.138	-0.003	0.378	0.448	-0.002
Age 40 years									
q_{ij}	0.012	0.012	0	0.003	0.005	-0.002	0.001	0.004	-0.003
$q_{..}$	0.013	0.017	-0.003	0.013	0.017	-0.001	0.013	0.017	-0.001
$m_{i.}$	2.545	1.003	0.005	0.952	1.003	0	0.377	0.638	-0.001
$m_{.j}$	3.119	5.230	-0.002	0.248	0.327	-0.001	0.248	0.327	0
m_{ij}	1.087	1.138	0	0.940	0.881	0	0.873	1.114	-0.001
Age 80 years									
q_{ij}	0.170	0.145	0.026	0.106	0.116	-0.010	0.063	0.111	-0.048
$q_{..}$	0.013	0.017	-0.046	0.013	0.017	-0.032	0.013	0.017	-0.025
$m_{i.}$	2.545	1.678	0.065	0.952	1.006	-0.006	0.377	0.638	-0.045
$m_{.j}$	8.548	6.611	0.039	8.468	6.611	0.027	8.468	6.611	0.021
m_{ij}	0.618	0.764	-0.033	1.033	1.026	0.001	1.560	1.537	0.001

SOURCE: AUTHOR

Figure 6: The difference in the age-specific probabilities of death (qij) between China and India, 1950–2021



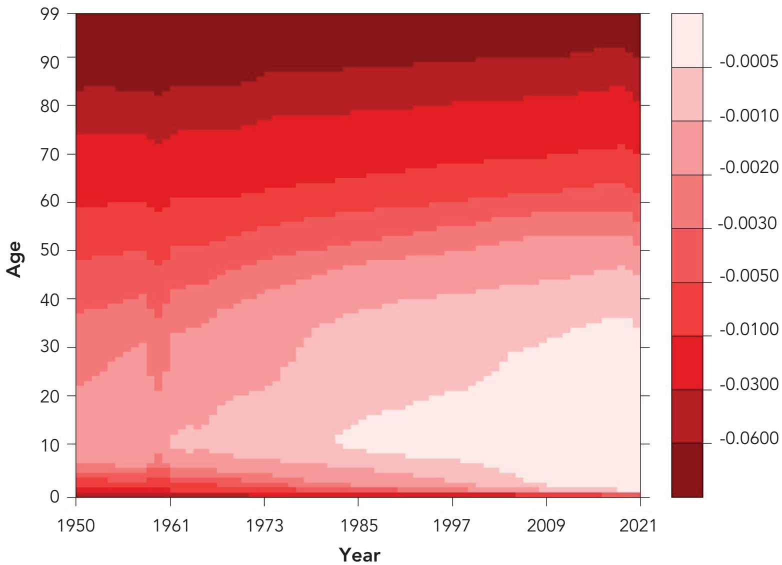
SOURCE: AUTHOR

The contribution of the difference in the four components – $q_{..}$, $m_{i.}$, $m_{.j}$ and m_{ij} – of q_{ij} to the difference in q_{ij} between China and India is summarised in Figures 7 through 10. The contribution of the difference in $q_{..}$ has always been negative as $q_{..}$ has always been lower in China than in India. However, this contribution increases with age, and has been the highest in the oldest ages both now and in the past. On the other hand, the contribution of the difference in $m_{i.}$, $m_{.j}$ and m_{ij} to the difference in q_{ij} between the two countries has been both negative and positive. The figures also suggest that there is a clear pattern in the contribution of the difference in $q_{..}$, $m_{i.}$ and $m_{.j}$, but the contribution of the difference in m_{ij} to the difference in q_{ij} has largely been different across time and age.

Table 4 shows how the difference in $q_{..}$, $m_{i.}$, $m_{.j}$ and m_{ij} has contributed to the difference in q_{ij} between China and India in selected years of life and in selected times. In the year 1950, the probability of death in the first year of life or in age

0 ($q_{1950,0}$) was 0.132 in China but 0.181 in India. This difference was due to higher overall mortality and higher age effect in India as the year or the time effect and the residual effect were lower in India than in China, which contributed to narrowing down the difference in the probability of death in the first year of life between the two countries in 1950. In 1985, $q_{1985,0}$ was 0.041 in China but 0.102 in India, and all the four components – $q_{..}$, $m_{i.}$, $m_{.j}$ and m_{ij} – contributed to lowering the probability of death in the first year of life in China as compared to that in India. A similar situation prevailed in 2021 when $q_{2021,0}$ was 0.006 in China but 0.026 in India. On the other hand, $q_{1950,40}$ was the same in the two countries because the negative difference in $q_{..}$ and $m_{.j}$ was offset by the positive difference in $m_{i.}$, but $q_{2021,40}$ was negative because $m_{i.}$ turned negative. Similar observations can be made about the difference in the probability of death at age 80.

Figure 7: Contribution of the difference in $q_{..}$ to the difference in q_{ij} between China and India

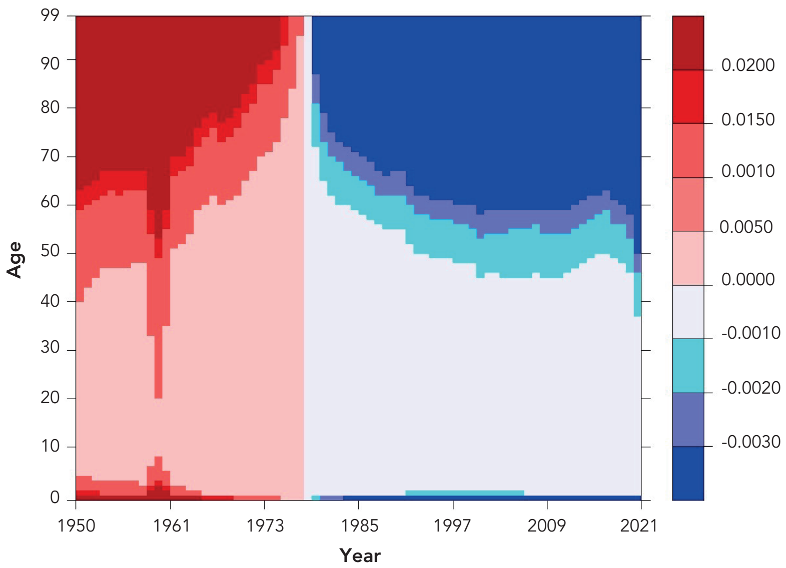


SOURCE: AUTHOR

Discussion and conclusions

This paper has highlighted the differences in mortality transition in China and India during the period 1950–2021. At the aggregate level, mortality transition has been more rapid in China. There are, however, ages at which the mortality transition in India has been more rapid relative to that in China. Mortality transition in China has not been limited to specific ages but has been spread across all ages up to 90 years of age. This has not been the case in India, where mortality transition has largely been confined to younger ages and there has been little transition in mortality in the ages 55–90. Mortality transition in younger ages, ages below 30 years, has been quite impressive in India, but the transition in younger ages in the country has been substantially compromised by very slow transition in older ages. The difference in mortality transition between China and India, then, is essentially located in the difference in mortality transition in older ages.

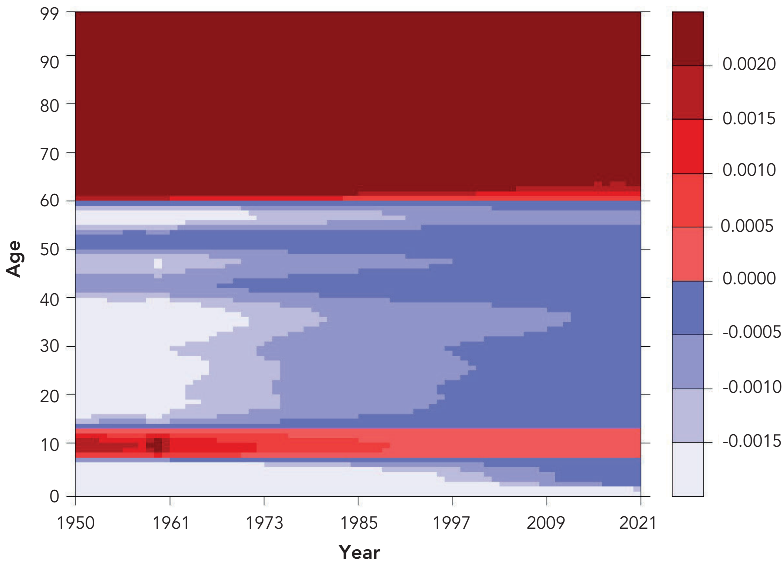
Figure 8: Contribution of the difference in $m_{i.}$ to the difference in q_{ij} between China and India



SOURCE: AUTHOR

The analysis also reveals that the impact of the COVID-19 pandemic on mortality has been much higher in India than that in China. This observation suggests that the health-care system in China, especially the public one, has been more efficient and effective in addressing the survival-related emergencies coming out of the pandemic than the health-care system in India. The almost universal coverage of China's public health-care system appears to have played a crucial role in preventing untimely deaths due to the pandemic. This does not appear to be the case with India. The life expectancy at birth in India is still around 70 years, which is low by international standards, while that in China compares with the life expectancy at birth in more developed countries of the world.

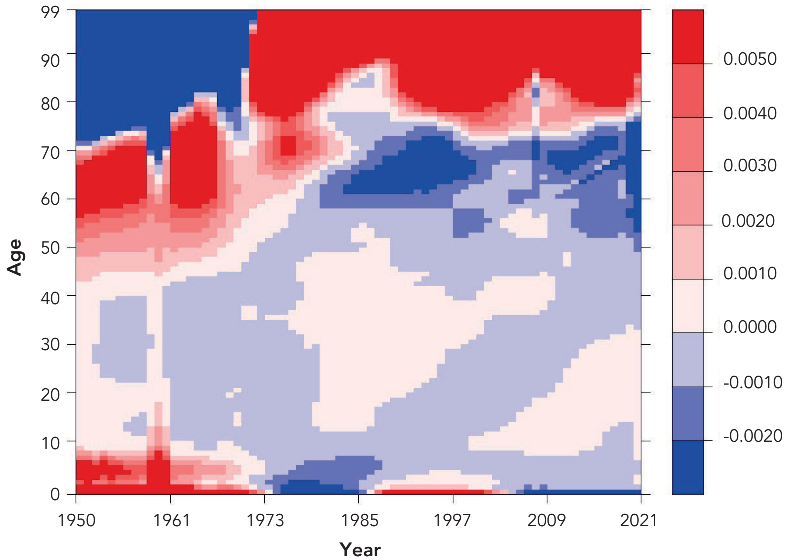
Figure 9: Contribution of the difference in $m_{.j}$ to the difference in q_{ij} between China and India



SOURCE: AUTHOR

India has now achieved replacement fertility, which means that an increasing proportion of the population of the country is getting older. The reduction in mortality in the younger ages will also hasten this process. The challenge for India, therefore, is to accelerate the reduction in mortality in older ages. This will require a reinvigoration of its health-care system, which has historically evolved following the extension approach of health services delivery, and it has primarily been directed towards addressing morbidity and mortality from infectious and communicable diseases through low-cost appropriate medical technology. This approach appears to have been successful in reducing the risk of death in younger ages, especially the risk of death during childhood. However, it has its limitations in addressing the health-care needs of the older population as non-communicable and degenerative diseases are the primary causes of morbidity and mortality in older ages. India needs an institution-based approach to meet the health-care needs of the old population, which will be increasing rapidly in the coming years.

Figure 10: Contribution of the difference in m_{ij} to difference in q_{ij} between China and India



SOURCE: AUTHOR

The present analysis also suggests that, at the aggregate level, mortality transition should be analysed in terms of the geometric mean of the age-specific probabilities of death and not in terms of the life expectancy at birth. Since the trend in the life expectancy at birth depicts mortality transition in a hypothetical population but not in the real population, as is the case with geometric mean of the age-specific probabilities of death. The trend in the life expectancy at birth is influenced by the age location of the mortality transition. If most of the mortality transition is confined to the younger ages of life, the improvement in the life expectancy at birth will be slower than when a mortality transition is well spread across all ages. In China, mortality transition has been fairly spread across the ages, whereas mortality transition in India has been confined largely to younger ages, and this appears to be a factor in the difference in the life expectancy at birth between the two countries. This weakness of the life expectancy at birth can be addressed by measuring mortality transition in terms of the geometric mean of the age-specific probabilities of death instead of the life expectancy at birth.

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APPENDIX

The change in the geometric mean of the age-specific probabilities of death (g) between two points in time, t_1 and t_2 (t_2>t_1), ∇g, can be written as:

$$\nabla g = g_2 - g_1 = \frac{g_2 - g_1}{ln\left(\frac{g_2}{g_1}\right)} \times ln\left(\frac{g_2}{g_1}\right) = l_{21} \times ln\left(\frac{g_2}{g_1}\right) \quad (1)$$

where

$$l_{21} = \frac{g_2 - g_1}{ln\left(\frac{g_2}{g_1}\right)} \quad (2)$$

is the logarithmic mean of g_2 and g_1 (Carlson, 1966, 1972; Bhatia, 2008; Ostle and Terwilliger, 1957; Lin, 1974). If q_i is the probability of death in age i, then

$$g = \left(\prod_{i=1}^{n} q_i\right)^{\frac{1}{n}} \quad (3)$$

$$ln\, ln\left(\frac{g_2}{g_1}\right) = ln\left(\frac{\left(\prod_{i=1}^{n} q_{2i}\right)^{\frac{1}{n}}}{\left(\prod_{i=1}^{n} q_{1i}\right)^{\frac{1}{n}}}\right) \quad (4)$$

$$ln\, ln\left(\frac{g_2}{g_1}\right) = \frac{1}{n}\sum_{i=1}^{n} ln\left(\frac{q_{2i}}{q_{1i}}\right) \quad (5)$$

Substituting,

$$\nabla g = g_2 - g_1 = \frac{l_{21}}{n} \times \sum_{i=1}^{n} ln\left(\frac{q_{2i}}{q_{1i}}\right) \quad (6)$$

Equation (6) decomposes the change in the geometric mean of the age-specific probabilities of death g into changes in the age-specific probabilities of death.

On the other hand, the difference in g between two populations, A and B, at time t_2 depends upon the difference in g between A and B at time t_1 and the difference in the change in g in A and B between t_1 and t_2 (Andreev et al., 2002; Jdanov et al., 2017). The difference in g between A and B at time t_2 may be written as:

$$\Delta g^2 = g_A^2 - g_B^2 = l_{AB}^2 \times ln\left(\frac{g_A^2}{g_B^2}\right) \quad (7)$$

where

$$l_{AB}^2 = \frac{g_A^2 - g_B^2}{ln\left(\frac{g_A^2}{g_B^2}\right)} \quad (8)$$

is the logarithmic mean of the g_A and g_B at time t_2. Now

$$ln\left(\frac{g_A^2}{g_B^2}\right) = ln\left(\frac{g_A^1}{g_B^1} \times \frac{g_B^1}{g_A^1} \times \frac{g_A^2}{g_B^2}\right) = ln\left(\frac{g_A^1}{g_B^1}\right) + ln\left(\frac{g_A^2}{g_A^1}\right) - ln\left(\frac{g_B^2}{g_B^1}\right) \quad (9)$$

Substituting in (8), I get

$$\Delta g^2 = g_A^2 - g_B^2 = l_{AB}^2 \times ln\left(\frac{g_A^1}{g_B^1}\right) + l_{AB}^2 \times ln\left(\frac{g_A^2}{g_A^1}\right) - l_{AB}^2 \times ln\left(\frac{g_B^2}{g_B^1}\right) \quad (10)$$

or

$$\Delta g^2 = g_A^2 - g_B^2 = \frac{l_{AB}^2}{n} \times \sum_{i=1}^{n} \quad ln\left(\frac{q_{1i}^A}{q_{1i}^B}\right) + \frac{l_{AB}^2}{n} \times \sum_{i=1}^{n} \quad ln\left(\frac{q_{2i}^A}{q_{1i}^A}\right) - \frac{l_{AB}^2}{n} \times \sum_{i=1}^{n} \quad ln\left(\frac{q_{2i}^B}{q_{1i}^B}\right) \quad (11)$$

Finally, the age-specific probability of death in the year i and age j, q_{ij}, can be modelled in terms of a common factor ($q_{..}$) across all i and j; a row- or year-specific factor ($q_{i.}$) which is common to all columns or ages, j, of the row or the year i; a column or age specific factor ($q_{.j}$) which is common to all rows or years, i, of the column or age, j, and a residual factor r_{ij}, which is specific to each pair of i and j as follows:

$$l_{ij} = q_{..} \times q_{i.} \times q_{.j} \times \frac{q_{ij}}{q_{..} \times q_{i.} \times q_{.j}} \quad (9)$$

or

$$q_{ij} = q_{..} \times \frac{q_{i.}}{q_{..}} \times \frac{q_{.j}}{q_{..}} \times \frac{q_{ij} \times q_{..} \times q_{..}}{q_{..} \times q_{i.} \times q_{.j}} \quad (10)$$

or

$$q_{ij} = q_{..} \times m_{i.} \times m_{.j} \times m_{ij} \tag{11}$$

where

$$m_{i.} = \frac{q_{i.}}{q_{..}} \tag{12}$$

$$m_{.j} = \frac{q_{.j}}{q_{..}} \tag{13}$$

$$m_{ij} = \frac{q_{ij} \times q_{..} \times q_{..}}{q_{..} \times q_{i.} \times q_{.j}} = \frac{\left(\frac{q_{ij}}{q_{..}}\right)}{\left(\frac{q_{i.}}{q_{..}} \times \frac{q_{i.}}{q_{..}}\right)} \tag{14}$$

Equation (11) suggests that difference in q_{ij} between two populations *A* and *B* can be decomposed into four components as follows:

$$\nabla q_{ij} = q_{ij}^{A} - q_{ij}^{B} = \left(q_{..}^{A} \times m_{i.}^{A} \times m_{.j}^{A} \times m_{ij}^{A}\right) - \left(q_{..}^{B} \times m_{i.}^{B} \times m_{.j}^{B} \times m_{ij}^{B}\right)$$

(15)

Now

$$\nabla q_{ij} = \frac{q_{ij}^{A} - q_{ij}^{B}}{ln\left(\frac{q_{ij}^{A}}{q_{ij}^{B}}\right)} \times ln\left(\frac{q_{ij}^{A}}{q_{ij}^{B}}\right) = \frac{q_{ij}^{A} - q_{ij}^{B}}{ln\left(\frac{q_{ij}^{A}}{q_{ij}^{B}}\right)} \times ln\left(\frac{q_{..}^{A} \times m_{i.}^{A} \times m_{.j}^{A} \times m_{ij}^{A}}{q_{..}^{B} \times m_{i.}^{B} \times m_{.j}^{B} \times m_{ij}^{B}}\right) \tag{16}$$

$$\nabla q_{ij} = \frac{q_{ij}^{A} - q_{ij}^{B}}{ln\left(\frac{q_{ij}^{A}}{q_{ij}^{B}}\right)} \times \left(ln\left(\frac{q_{..}^{A}}{q_{..}^{B}}\right) + ln\left(\frac{m_{i.}^{A}}{m_{i.}^{B}}\right) + ln\left(\frac{m_{.j}^{A}}{m_{.j}^{B}}\right) + ln\left(\frac{m_{ij}^{A}}{m_{ij}^{B}}\right)\right) \tag{17}$$

$$\Delta q_{ij} = \left\{\frac{q_{ij}^{A} - q_{ij}^{B}}{ln\left(\frac{q_{ij}^{A}}{q_{ij}^{B}}\right)} \times ln\left(\frac{q_{..}^{A}}{q_{..}^{B}}\right)\right\} + \left\{\frac{q_{ij}^{A} - q_{ij}^{B}}{ln\left(\frac{q_{ij}^{A}}{q_{ij}^{B}}\right)} \times ln\left(\frac{m_{i.}^{A}}{m_{i.}^{B}}\right)\right\} + \left\{\frac{q_{ij}^{2} - q_{ij}^{1}}{ln\left(\frac{q_{ij}^{2}}{q_{ij}^{1}}\right)} \times ln\left(\frac{m_{.j}^{2}}{m_{.j}^{1}}\right)\right\} + \left\{\frac{q_{ij}^{2} - q_{ij}^{1}}{ln\left(\frac{q_{ij}^{2}}{q_{ij}^{1}}\right)} \times ln\left(\frac{m_{ij}^{2}}{m_{ij}^{1}}\right)\right\}$$

$$\Delta q_{ij} = C_{..} + C_{i.} + C_{.j} + C_{ij} \tag{18}$$

$$C_{..} = \left\{\frac{q_{ij}^{A} - q_{ij}^{B}}{ln\left(\frac{q_{ij}^{A}}{q_{ij}^{B}}\right)} \times ln\left(\frac{q_{..}^{A}}{q_{..}^{B}}\right)\right\} \tag{19}$$

$$C_{i.} = \left\{ \frac{q_{ij}^{A} - q_{ij}^{B}}{ln\left(\frac{q_{ij}^{A}}{q_{ij}^{B}}\right)} \times ln\left(\frac{m_{i.}^{A}}{m_{i.}^{B}}\right) \right\} \tag{20}$$

$$C_{.j} = \left\{ \frac{q_{ij}^{2} - q_{ij}^{1}}{ln\left(\frac{q_{ij}^{2}}{q_{ij}^{1}}\right)} \times ln\left(\frac{m_{.j}^{2}}{m_{.j}^{1}}\right) \right\} \tag{21}$$

$$C_{ij} = \left\{ \frac{q_{ij}^{2} - q_{ij}^{1}}{ln\left(\frac{q_{ij}^{2}}{q_{ij}^{1}}\right)} \times ln\left(\frac{m_{ij}^{2}}{m_{ij}^{1}}\right) \right\} \tag{22}$$

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