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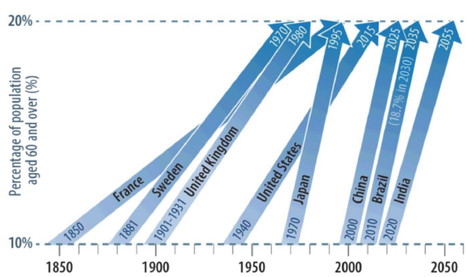
The Acceleration of Population Ageing

The number and proportion of people age 60 and over in the population is increasing.



Time for percentage of population **over age 60** to double

Preplanned Studies

Methods and Applications

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Cover Image: adapted from the World Health Organization, https://www.who.int/multi-media/details/speed-of-population-ageing.

Preplanned Studies

Age-Period-Cohort Analysis on Long-Term Mortality Trend of Genitourinary Diseases — China, 1987–2021

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Summary

What is already known about this topic?

There has been a lack of attention to genitourinary diseases for an extended period, resulting in limited research on the mortality trends of genitourinary diseases in China.

What is added by this report?

This study examines the long-term trend of genitourinary diseases' mortality across Chinese individuals of all genders and in various urban and rural regions. Additionally, it investigates the impact of age-period-cohort effects on this trend.

What are the implications for public health practice?

It is imperative to address genitourinary diseases, particularly among vulnerable populations such as rural older men. Policymakers should prioritize these individuals by providing necessary policy interventions and healthcare support.

Genitourinary diseases have been understudied despite being a significant public health issue (*1*). Epidemiological research indicates that these diseases are associated with aging and metabolic conditions like hypertension, diabetes, and metabolic syndrome (*2*). With China's transition to an aging society and the rise of non-communicable diseases due to industrialization and changing dietary habits and lifestyles (*3–4*), it becomes crucial to assess the mortality trends of genitourinary diseases in the country. Thus, this study analyzed genitourinary disease mortality data from 1987 to 2021, obtained from the National Health Commission's (NHC) death registration system. Joinpoint regression analysis and age-period-cohort models were employed to identify the long-term trends in genitourinary disease mortality rates among the Chinese population and explore age-period-cohort effects. The findings from this study indicate a downward trend in age-standardized mortality rate (ASMR) for genitourinary diseases, although the crude mortality rates showed a slight decline. It is evident that proactive measures need to be taken to address genitourinary diseases, with a specific focus on the burden in men and the elderly, thus providing policymakers with valuable insights while formulating appropriate strategies.

The age-specific mortality data for genitourinary diseases from 1987 to 2021 were obtained from China's NHC death registration system. The data were collected from various administrative organizations (*5*). Deaths were classified according to the 9th revision of the International Classification of Disease (ICD-9) before 2002 and ICD-10 thereafter. ASMRs were calculated using the World Standard Population (*6*). A joinpoint regression model with natural log-transformed rates was used to analyze the mortality trends of genitourinary diseases between 1987 and 2021. The Joinpoint Regression Program (version 4.9.10, Statistical Research and Applications Branch National Cancer Institute, Washington, USA) was employed for this analysis. Annual percentage changes (APCs) and average annual percentage changes (AAPCs) were calculated, along with 95% confidence intervals (*CIs*) for the entire study period. To address the exact collinearity among the effects of age, period, and cohort, the age-period-cohort model was utilized. This model employed a web tool developed by the U.S. National Cancer Institute. The net drifts were estimated to determine the annual percentage change for the entire population, while the local drifts represented the annual percentage change for each age group. Statistical significance was defined as a two-tailed *P*-value <0.05.

Table 1 displays the results of the joinpoint regression, showing the long-term trends of crude mortality rates and ASMRs for genitourinary diseases among Chinese individuals by sex and area. From 1987 to 2021, the crude mortality of genitourinary diseases declined slightly, whereas the ASMRs decreased substantially by sex and both urban and rural areas. The ASMR of genitourinary diseases decreased at a rate of −2.9% annually in urban areas and −2.2% annually in rural areas. However, the

TABLE 1. Joinpoint analysis of crude and age-standardized mortality rates of genitourinary diseases in urban and rural areas.

Categories	Mortality rate (per 100,000)		Total study period		Period 1		Period 2		Period 3	
	1987	2021	AAPC (%)	95% *CI*	Years	APC (%)	Years	APC (%)	Years	APC (%)
Crude mortality										
Genitourinary diseases in urban areas										
Total	10.05	6.75	−0.9*	(−1.4, −0.5)	1987–2004	−0.4	2004–2012	−3.8*	2012–2021	0.7
Male	10.29	7.94	−0.5	(−1.1, 0.0)	1987–2004	−0.1	2004–2011	−3.7*	2011–2021	1.1*
Female	9.80	5.56	−1.4*	(−1.9, −1.0)	1987–2004	−0.7*	2004–2012	−4.4*	2012–2021	−0.3
Genitourinary diseases in rural areas										
Total	8.08	7.86	−0.2	(−0.8, 0.4)	1987–1999	0.8	1999–2008	−4.1*	2008–2021	1.6*
Male	8.99	9.34	−0.1	(−0.9, 0.7)	1987–2000	0.9*	2000–2005	−6.7*	2005–2021	1.2*
Female	7.14	6.32	−0.4	(−1.2, 0.4)	1987–2000	0.5	2000–2008	−5.0*	2008–2021	1.6*
Age-standardized mortality										
Genitourinary diseases in urban areas										
Total	13.48	4.04	−2.9*	(−4.5, −1.3)	1987–2005	−1.9*	2005–2008	−14.1	2008–2021	−1.6*
Male	14.86	5.19	−2.8*	(−4.4, −1.2)	1987–2005	−2.2*	2005–2008	−13.9	2008–2021	−1.0*
Female	11.50	3.02	−3.2*	(−4.7, −1.7)	1987–2005	−1.8*	2005–2008	−14.4	2008–2021	−2.5*
Genitourinary diseases in rural areas										
Total	10.33	4.91	−2.2*	(−2.9, −1.5)	1987–2000	−0.4	2000–2008	−6.4*	2008–2021	−1.4*
Male	12.56	6.34	−2.3*	(−3.4, −1.2)	1987–2001	−0.8	2001–2005	−9.7*	2005–2021	−1.8*
Female	8.84	3.65	−2.4*	(−3.2, −1.5)	1987–2000	−0.3	2000–2008	−6.8*	2008–2021	−1.6*

Abbreviation: APC=annual percent change; AAPC=average annual percent change; *CI*=confidence interval.
* $P<0.05$.

decline in crude mortality among urban males and rural residents of both sexes was not statistically significant.

Figure 1 shows the age, period, and cohort effects on mortality from genitourinary diseases. After adjusting for period effects, the age effects demonstrate that the mortality of genitourinary diseases increases with age group and grows more rapidly in older age groups, with males having a higher rate than females. The period effects reveal a declining pattern for both males and females in urban and rural areas. In each subgroup, the period 1987–1992 has the highest risk, and taking the period 2002–2007 as the reference, the relative risk (RR) is 1.32 (95% *CI*: 1.24, 1.40) in urban males, 1.61 (95% *CI*: 1.52, 1.72) in urban females, 1.61 (95% *CI*: 1.49, 1.73) in rural males, and 1.73 (95% *CI*: 1.61, 1.87) in rural females. The cohort effects indicate that the older birth cohort has a greater risk across subgroups, with the 1902 cohort (born between 1900 and 1904) having the highest risk, with a risk ratio of 7.71 (95% *CI*: 6.79, 8.76) for urban males, 9.00 (95% *CI*: 7.76, 10.43) for urban females, 5.84 (95% *CI*: 4.92, 6.94) for rural males, and 6.32 (95% *CI*: 5.30, 7.53) for rural females, taking the 1962 cohort (born between 1960 and 1964) as the reference. The lowest risk is found in the 2017 cohort (born between 2015 and 2019).

Figure 2 presents the net drift and local drift for genitourinary diseases. The net drift was −4.16% (95% *CI*: −4.38, −3.94) in urban areas, with −3.59% (95% *CI*: −3.85, −3.34) for males and -4.82% (95% *CI*: −5.11, −4.52) for females. In rural areas, it was −3.66% (95% *CI*: −3.94, −3.38), with −3.34% (95% *CI*: −3.64, −3.05) for males and -4.05% (95% *CI*: −4.37, −3.73) for females. The local drifts were below 0 in all age groups.

DISCUSSION

The study findings showed a modest decrease in crude mortality rates and a significant decline in ASMR for genitourinary diseases over the study period. These results demonstrate the improvement in healthcare conditions in China, leading to a decrease in mortality rates for genitourinary diseases across different age groups, genders, and urban-rural areas. However, as the population in China continues to age, it highlights the need for increased attention to

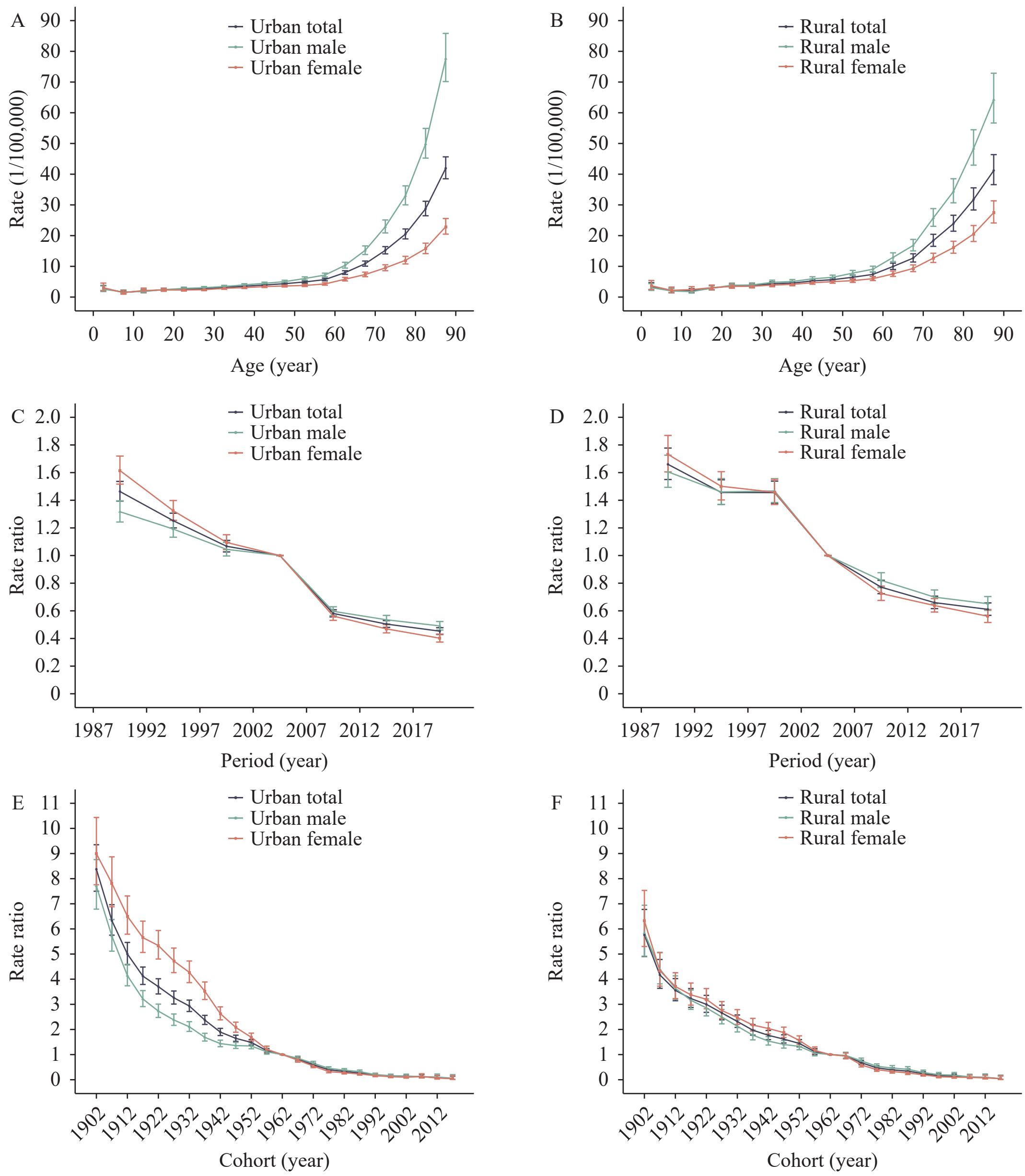

FIGURE 1. Age, period, and cohort effects on genitourinary diseases' mortality rate in rural-urban China from 1987 to 2021. (A) Age effects on mortality rates in urban China; (B) Age effects on mortality rates in rural China; (C) Period effects on mortality rates in urban China (D) Period effects on mortality rates in rural China; (E) Cohort effects on mortality rates in urban China; (F) Cohort effects on mortality rates in rural China.

genitourinary diseases.

Mortality rates for genitourinary diseases were higher in males than females in both urban and rural areas. However, there were notable period and cohort effects indicating that women experienced a greater reduction in genitourinary disease mortality from 1987 to 2021. These findings underscore the need to prioritize genitourinary diseases in males. Notably, older males derived greater benefits compared to older women, which could be attributed to a more pronounced mortality gap in elderly adults. Regarding urban and rural areas, we observed a crossover pattern where crude mortality and ASMR for genitourinary diseases were initially lower in rural China in 1987 but higher in 2021 compared to urban China. Notably, the crude mortality rate from genitourinary diseases in rural males increased between 1987 and 2021. This highlights that improved medical care has not offset the increased risk of death from aging and lifestyle changes in Chinese rural men. Consequently, policymakers should prioritize genitourinary diseases in vulnerable populations, particularly rural older men.

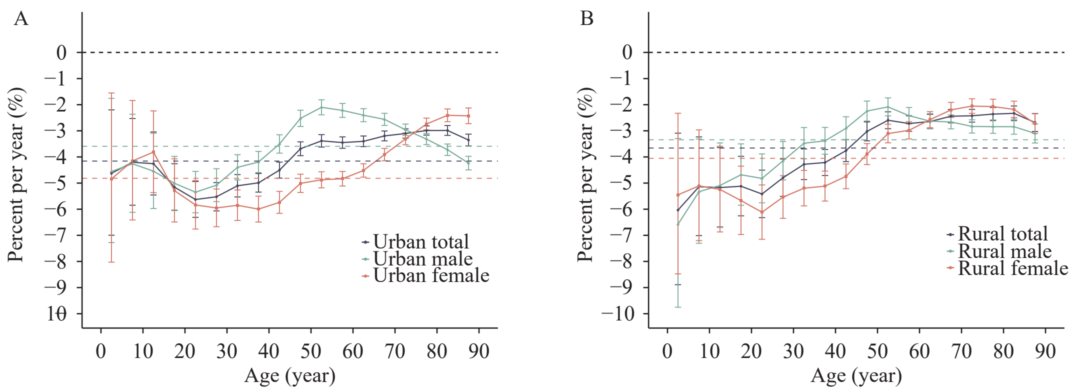

FIGURE 2. Local drift and net drift for genitourinary diseases' mortality and rural-urban difference by sex in China from 1987 to 2021. (A) In urban China; (B) In rural China.

In the context of aging and lifestyle changes, cardiovascular and cerebrovascular diseases, as well as cancers, have traditionally been the focus of researchers. However, our analysis also revealed a decline in ASMRs of genitourinary diseases. Nonetheless, it is important not to underestimate the impact of genitourinary diseases. First, it should be noted that the mortality rate of genitourinary diseases is higher in the elderly. Given the current trend of population aging in China, the risk of mortality from genitourinary diseases is expected to increase. Second, the global rise in heat waves presents a potential concern for an associated increase in mortality rates related to genitourinary illnesses (*7*). This can be attributed to the heightened risk of renal dysfunction resulting from hyperthermia and dehydration due to prolonged exposure to high temperatures (*8*). Furthermore, previous research has shown a significant increase in various mortality patterns in countries with low death rates over the past two decades. The percentage of deaths attributed to circulatory diseases has decreased, while the proportion of deaths attributable to other causes, including genitourinary diseases, has increased (*9*). As China moves towards being a low-mortality country, it is imperative and urgent to address genitourinary diseases at an earlier stage.

Several limitations exist in this study. First, the results were obtained from surveillance data rather than cohort data, which restricts our analysis to population-level trends rather than individual-level analysis. Second, the death categories were coded using ICD-9 prior to 2002, but ICD-10 coding was used thereafter. This may have introduced challenges in aligning the data with genitourinary disease trends, although previous research has indicated minimal impact from the transition from ICD-9 to ICD-10 (*10*).

Conflicts of interest: No conflicts of interest.

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Preplanned Studies

Changing Patterns of Injury Mortality Among the Elderly Population in Urban and Rural Areas — China, 1987–2021

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Summary

What is already known about this topic?

Injury is a significant public health issue, particularly among the elderly population. However, the extent of this problem varies significantly based on age, gender, and geographic location.

What is added by this report?

This study aims to examine the changing patterns of injury mortality rates in China over a 35-year period and assess the age-period-cohort effects on mortality trends.

What are the implications for public health practice?

This study examines the evolving patterns of injury mortality in the elderly population and identifies potential high-risk groups. The findings offer valuable insights for informing injury prevention policies.

Injuries pose a significant public health challenge, accounting for 10.6% of the global burden of disease (*1*). The elderly population, due to their diminished ability to control their surroundings, are particularly vulnerable to injuries. In fact, injuries are the second leading cause of death among the elderly, resulting in substantial burden and economic loss for individuals, families, and society as a whole (*2*–*3*). Given the rapid growth of China's aging population, these burdens are expected to escalate, underscoring the need for research on elderly injuries (*4*–*5*). Previous studies have shown a downward trend in injury-related mortality among Chinese elderly individuals (*6*). However, there is limited documentation on the long-term patterns of urban-rural disparities in injury mortality by age, period, and cohort (*7*). This study aims to examine the changing patterns of injury mortality among the elderly in China from 1987 to 2021, while also identifying the age-period-cohort effects on mortality changes. The findings of this study will provide valuable data for informing the development of injury intervention policies by relevant national agencies.

The injury mortality rates were derived from the death registration system of the National Health Commission in China, as previously described (*8*). Age-standardized mortality rates (ASMR) per 100,000 population were calculated using the direct method and the World Standard Population as a reference. To identify temporal trends in injury ASMR, a Joinpoint regression model was employed. Furthermore, the age-period-cohort model was used to assess the individual effects of age, period, and birth cohort on injury mortality rates in China (*9*).

The present study discovered a gradual decrease in injury-related mortality rates among the elderly population in China over a span of 35 years. It is noteworthy that older age, male gender, and residing in rural areas all contribute to a higher risk of injury-related death among the elderly. Although there is a contrasting trend in injury mortality rates between urban and rural areas for the elderly, the disparities in period effects and cohort effects are minimal.

Figure 1 shows long-term trends in ASMR for injury in China's urban and rural populations by sex from 1987 to 2021. The ASMR from injuries among the elderly largely maintained a gentle decline from 1987 to 2002, except for a rebound period (1996–1998) in rural males. From 2002 to 2006, the ASMR for urban elderly males and females experienced two significant fluctuations, while the rate for rural elderly declined more rapidly. Subsequently, the ASMR for urban and rural elderly exhibited a slight increase. There was a fluctuation characterized by an initial decrease followed by an increase around 2010, and the rate has since remained broadly stable.

The joinpoint results are presented in Table 1. Overall, there was a slight decrease in injury ASMR in both urban and rural areas, although the substage trends varied. In urban areas, ASMR showed a relatively marked decline from 1987–2008, then a slight rebound from 2008–2021. In contrast, ASMR in rural areas showed a slight decline from 1987–2006, and finally a nearly flat rebound from 2006–2021. In addition, all annual percent changes between sexes indicated a slight urban-rural disparity.

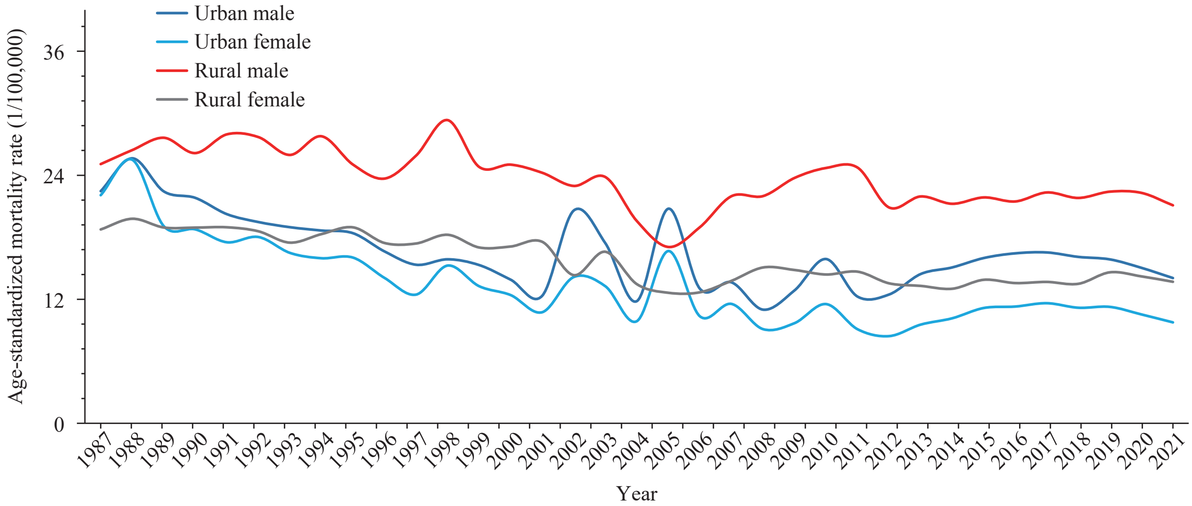

FIGURE 1. Trends in age-specific standardized mortality rates of injury among the elderly in urban and rural China by sex: 1987–2021.

TABLE 1. Joinpoint analysis of age-standardized mortality rates from injury in urban and rural areas.

Residence	Mortality rate† (per 100,000)		Entire range§		Segment 1			Segment 2		
	1987	2021	AAPC (%)	95% *CI*	Period	APC (%)	95% *CI*	Period	APC (%)	95% *CI*
Urban										
Total	22.28	11.84	−1.5*	(−2.6, −0.6)	1987−2008	−3.2*	(−4.1, −2.3)	2008−2021	1.3	(−0.7, 3.3)
Male	22.47	14.06	−1.0*	(−1.9, −0.0)	1987−2008	−2.6*	(−3.6, −1.6)	2008−2021	1.7	(−0.3, 3.8)
Female	22.08	9.77	−1.9*	(−2.8, −1.0)	1987−2009	−3.4*	(−4.3, −2.6)	2009−2021	1.0	(−1.2, 3.2)
Rural										
Total	21.78	17.32	−0.9*	(−1.5, −0.4)	1987−2006	−1.7*	(−2.2, −0.9)	2006−2021	−0.1	(−1.1, 0.8)
Male	25.08	21.09	−0.7*	(−1.2, −0.3)	1987−2005	−1.5*	(−2.1, −0.8)	2005−2021	0.1	(−0.7, 0.9)
Female	18.76	13.70	−1.2*	(−1.6, −0.7)	1987−2006	−1.9*	(−2.4, −1.4)	2006−2021	−0.2	(−1.0, 0.5)

Abbreviation: APC=annual percent change; AAPC=average annual percent change; *CI*=confidence interval.
* *P*<0.05.
† Standardization employed is based on the world standard population from the World Health Organization.
§ The time frame considered ranges from 1987 to 2021.

Figure 2 depicts the net drift and local drift of mortality rates for injury. Both net drift and local drift were calculated separately in the APC model. Net drift represents the time-trend effect on the entire population, while local drift indicates the log-linear trend specific to each age group. In both rural and urban areas of China, there was a similar net drift pattern, with a significant decrease in injury mortality rates over the study period. The decline in mortality rates was more pronounced for females compared to males, both in urban areas (females: −2.12% *vs.* males: −1.12%) and rural areas (females: −1.33% *vs.* males: −0.77%). Notably, the local drift curves in urban and rural areas exhibited contrasting patterns. In urban areas, the decline in injury-related mortality became increasingly pronounced with age among the elderly, whereas in rural areas, the opposite trend was observed.

Figure 3 shows the estimates of age, period, and cohort effects on mortality rates for injuries. Age effect patterns are consistent across sexes, as well as urban and rural areas. The older the age group among the elderly, the higher the mortality. The mortality rate for males is generally higher than that for females, but this sex difference is gradually narrowing. However, the mortality rate for rural elderly individuals is consistently higher than that for the corresponding urban group. Period effects in urban and rural areas are largely consistent, except for the period from 2002–2007. Additionally, the earlier the birth cohort, the higher the mortality rate, whether in urban or rural areas. For the birth cohorts between 1902 and 1927, the urban areas consistently have a higher mortality rate compared to rural areas.

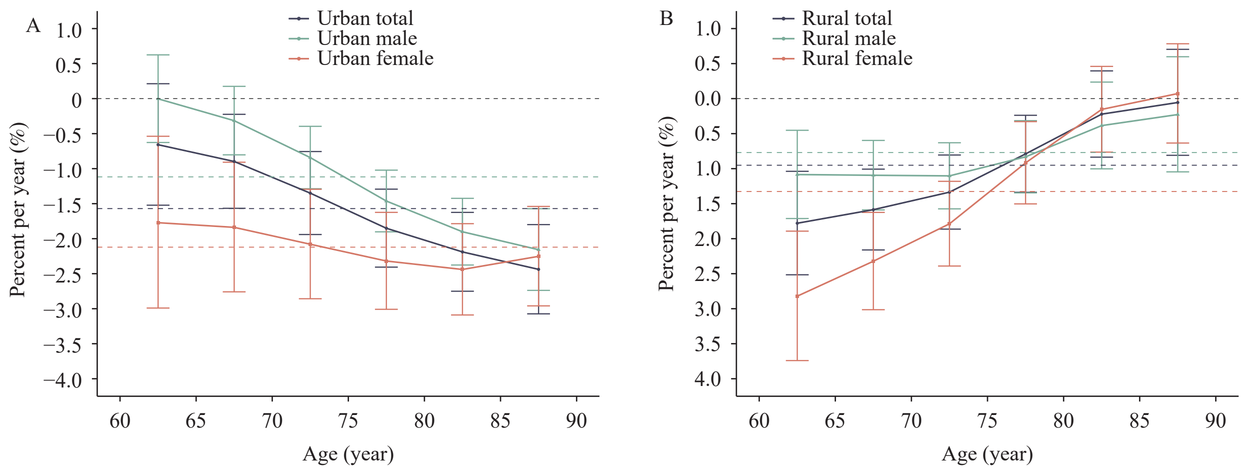

FIGURE 2. Local drift with net drift values for injury mortality rates and sex disparity by area in China from 1987 to 2021. (A) Net and local drifts in urban areas; (B) net and local drifts in rural areas.

DISCUSSION

This study examines the long-term trends in injury mortality rates among the elderly population in China over a span of 35 years, with a focus on the urban-rural divide. Our findings reveal several important insights. Firstly, we observed a gradual decrease in elderly injury mortality rates in China over the past 35 years, although there has been a recent minor increase. Secondly, specific high-risk groups for injuries include the older population, males, and rural elderly individuals. Thirdly, the decline in injury mortality rates in urban and rural areas follows opposite patterns: in urban areas, mortality rates decrease more with advancing age, while in rural areas, the trend is reversed. Moreover, both urban and rural settings display similar period and cohort effects. These findings underscore the need for tailored injury prevention programs targeting high-risk elderly groups.

The decrease in mortality rates related to injuries in the elderly population demonstrates improvement in prevention strategies, which can be attributed to various factors. These include enhanced medical access and services resulting from economic growth, making previously fatal injuries treatable. Additionally, expanded public health services and social security have improved healthcare for the elderly, particularly for high-risk groups (*6*). Moreover, increased health education initiatives have raised awareness and led to a reduction in accidental injuries. However, this declining trend has reached a plateau, evidenced by a recent slight increase, particularly among urban males. This may be attributed to China's aging population and the ongoing process of urbanization, which exposes elderly males residing in urban areas to greater environmental hazards and an increased risk of injury.

The impact of age on injury-related mortality among the elderly in China has been identified as significant (*10*). A notable age disparity in injury mortality rates was observed, with rates increasing exponentially with age (*6*,*10*). This finding suggests that the older-age elderly are at a higher risk for injuries, potentially due to factors such as declining physical function, pre-existing health conditions, cognitive decline, and sensory impairments. These factors make them more vulnerable to accidents, including falls, traffic accidents, fires, crushing injuries, poisoning, suicide, and other forms of injury (*10*). Consequently, there is a need for increased attention and targeted efforts towards injury prevention among the older elderly population.

Sex disparity and urban-rural disparity in injury mortality rates are apparent (*7*,*10*). Males, particularly in rural areas, face the highest risk of injury, likely due to their participation in outdoor activities that increase exposure to injury hazards (*6*). Inadequate treatment for injuries among rural elderly can be attributed to limited access to medical resources and lower economic and educational levels. Additionally, the migration of younger, middle-aged workers to cities as a result of urbanization often leaves elderly individuals in rural areas lacking sufficient care. However, the implementation of China's Healthy Aging initiatives aimed at improving rural healthcare is expected to reduce the urban-rural disparity in injury mortality (*4*,*5*,*10*).

The overall injury mortality rate among the elderly is decreasing, with variations observed across different

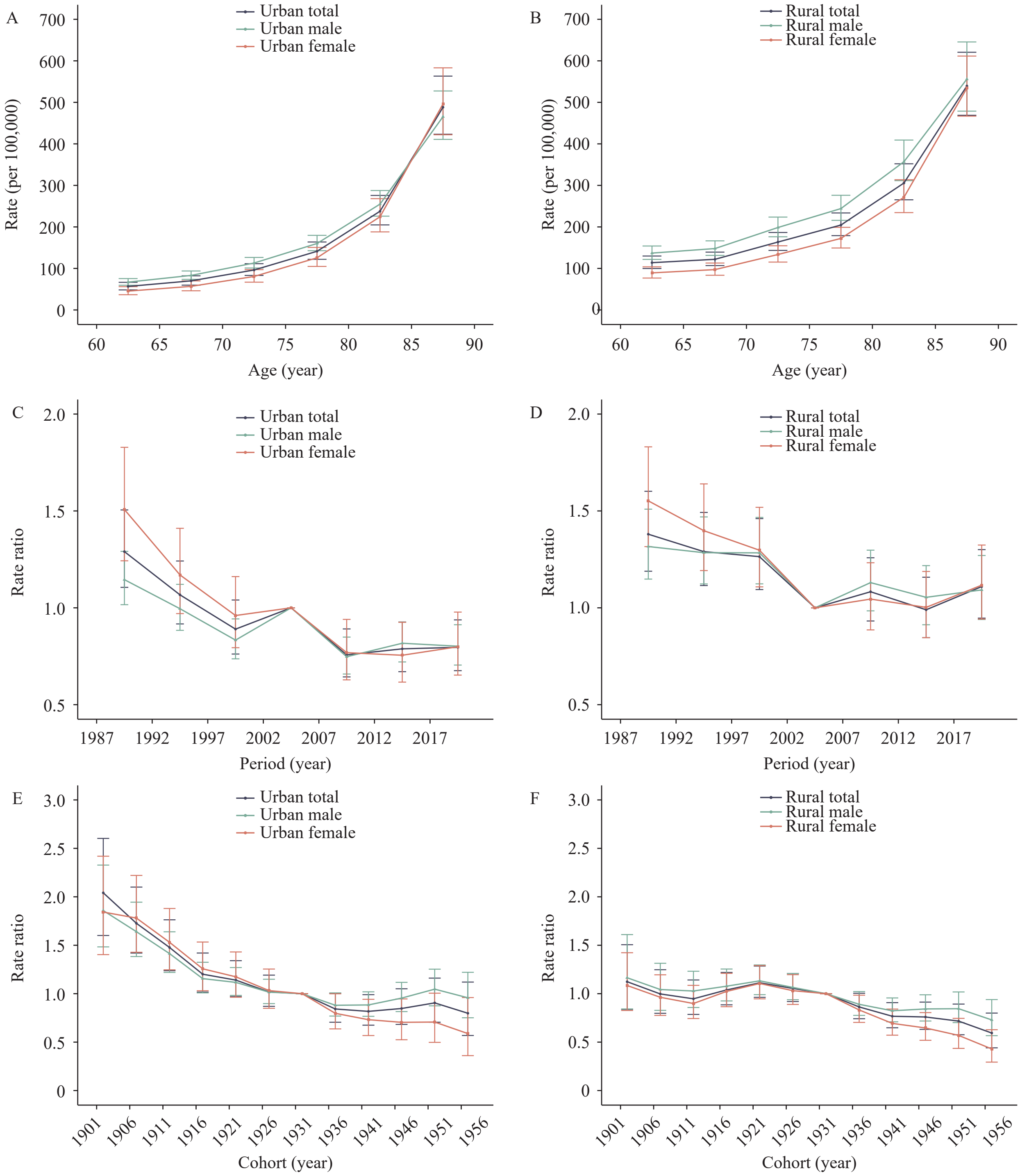

FIGURE 3. The effects of age, period, and cohort on age-standardized mortality rates due to injury among the elderly in China from 1987 to 2021. (A) Age effects in urban areas; (B) age effects in rural areas; (C) period effects in urban areas; (D) period effects in rural areas; (E) cohort effects in urban areas; (F) cohort effects in rural areas.

demographic groups. Females exhibit a more rapid decline in mortality rates compared to males, potentially due to factors such as reduced exposure to high-risk activities and advancements in education and social status over the past three decades. Rural elderly individuals also experience a faster decline in mortality rates compared to their urban counterparts, which can be attributed to notable improvements in rural healthcare services. In urban areas, injury mortality rates decline more rapidly with age, likely due to better access to medical resources, safety facilities, and educational initiatives. Conversely, in rural areas, younger elderly individuals engaged in hazardous activities may face higher risks, but these risks decrease as they age and retire from such tasks. However, due to limited availability of medical resources, particularly those tailored to the elderly population, the decline in injury mortality may be slower for older elderly individuals residing in rural areas.

Period effects demonstrate a decline in injury mortality among the elderly over time (*6*). Higher mortality rates in earlier birth cohorts suggest that improvements in medical resources and social services have contributed to the reduction in injury mortality. Notably, urban earlier cohorts had higher mortality rates compared to their rural counterparts, possibly due to their exposure to events such as World War II and the Chinese Civil War, which resulted in more conflicts and subsequently increased physical and psychological injuries among urban elderly.

The study has several limitations that must be taken into account. First, the lack of detailed data on specific types of injury hampers the ability to develop more targeted prevention strategies. Second, the dataset used in this study is subject to underreporting, with an estimated underreporting rate of approximately 2%, potentially leading to an underestimation of mortality. Lastly, as with other age-period-cohort studies, there is a possibility of ecological fallacy in our results, which means that findings at the population level may not always be applicable to individuals.

Conflicts of interest: No conflicts of interest.

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Preplanned Studies

A Multi-Center Cross-Sectional Study on Visual Impairment and Depression Among Students — Jiangsu Province, China, 2017–2022

Xiyan Zhang[1,2]; Wei Du[3]; Yan Wang[1]; Wenyi Yang[1]; Xin Wang[1]; Jie Yang[1,2,#]

Summary

What is already known about this topic?

China exhibits a significantly high prevalence of myopia compared to other countries globally. Children with vision impairment have been found to engage less in physical activities, achieve lower academic performance, and have increased vulnerability to depression.

What is added by this report?

During a six-year observational study, a population-level correlation was identified between varying degrees of visual impairment and the presence of depressive symptoms among students. Specifically, individuals with a visual acuity below 4.0 had a significantly higher odds ratio of 1.90 (95% confidence interval: 1.53–2.37) compared to individuals with normal vision (visual acuity ≥5.0).

What are the implications for public health practice?

This study highlights the importance of holistic health interventions that address both visual and psychological aspects. Understanding common mechanisms and influential factors can guide the development of more impactful public health strategies.

Vision impairment is a significant global issue, affecting 2.2 billion individuals worldwide, including an estimated 19 million children aged 0–14 years. Of this group, approximately 1.4 million children suffer from irreversible blindness (*1*). In China, over half of children aged 6–18 years are affected by myopia, which can be attributed to the high-pressure educational environment they face (*2*). This vision impairment can have detrimental effects on their education and may contribute to the development of depressive symptoms (*2*). As vision is crucial for perceiving and comprehending the environment, impairments in this modality can negatively impact mental health, leading to anxiety, depression, or self-esteem issues. Particularly in the eastern China, where myopia prevalence is highest among children and adolescents, the link between visual health and psychological well-being is a significant public health concern that requires further investigation and ongoing attention.

The study was conducted from 2017 to 2022, with participation from 11 project sites. Random sampling of districts or counties was used to select these sites in Jiangsu Province, which consists of 98 districts or counties. During the research period, a total of 8,997 middle and high school students across 6 grade levels participated in the survey. For more detailed information on the survey process (Figure 1).

The survey comprised several components. First, ophthalmic examinations were conducted by trained program members, nurses, and doctors. The myopia screening institution needed to have a valid medical institution license. Visual impairment, referred to as low vision, was assessed using the "Standard Logarithmic Visual Acuity Chart" (GB 11533–2011) (*3*). Visual acuity of 5.0 or more indicated health vision in children and adolescents aged 6 and above. Visual acuity ranging from 4.6 to 4.9 was considered as mild to moderate visual impairment, while visual acuity equal to or less than 4.5 was classified as severe visual impairment. The severe visual impairment group was further categorized into severe vision impairment group 1 (visual acuity ≤4.0) and severe vision impairment group 2 (visual acuity ranging from 4.1 to 4.5). Second, height and weight measurements were taken. Students removed their shoes and clothes before their weight and height were measured. The measurements were taken according to the standardized equipment and procedures outlined in the health check list for primary and junior school students (GB 16134–2011) (*4*). Overweight, obesity, and body mass index (BMI) screening followed the unified classification criteria based on the screening for overweight and obesity among school-age children and adolescents (WST 586–2018) issued by the National

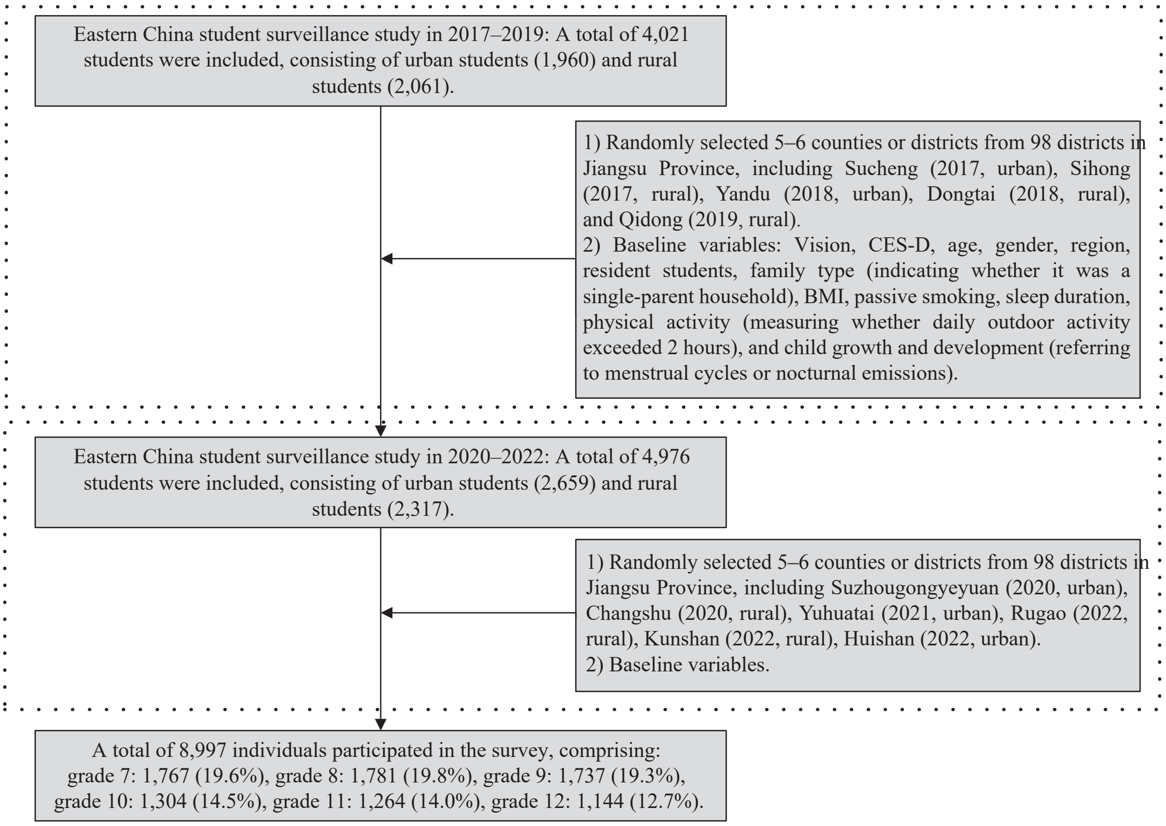

FIGURE 1. The flowchart illustrates the research procedure involving middle and high school students from 2017 to 2022.
Abbreviation: CES-D=Center for Epidemiologic Studies Depression Scale; BMI=body mass index.

Health Commission of the People's Republic of China. BMI was calculated as weight in kilograms divided by height in meters squared. Third, the prevalence of depressive symptoms was assessed using the Center for Epidemiologic Studies Depression Scale (CES-D) (*5*). The CES-D scale, which has been widely used and validated for reliability in Chinese cohorts, was utilized. The Chinese version of the CES-D scale employs a four-point Likert scale, with higher scores indicating more severe depressive symptoms. A CES-D score of 20 or higher was used as the threshold to identify the presence of depressive symptoms (*6*). Finally, a comprehensive questionnaire was administered to collect baseline data, including information on date of birth, family structure, outdoor activity levels, exposure to passive smoking, and other relevant factors.

The characteristics of the participating students were described as follows: 1) Continuous variables such as age, BMI, and sleep duration, which followed a normal distribution, were presented as mean±standard deviation. 2) Categorical variables, including resident students, single-parent household, and passive smoking, were analyzed using chi-square tests and presented as percentages. 3) Multilevel logistic models were used to investigate the association between visual impairment and symptoms of depression. The analysis included the following covariates: age, gender, region, resident students, family type (single-parent household), BMI, passive smoking, sleep duration, physical activity (more than 2 hours of daily outdoor activity), child growth development, and year. Odds ratios (*OR*s) along with their corresponding 95% confidence intervals (*CI*s) were calculated. Data analysis was performed using IBM SPSS (version 20.0; IBM Corp., Armonk, NY, US). Statistically significant results were defined as *P*-value <0.05.

This study included 8,997 participants between 2017 and 2022. The average age of the participants was 14.4±1.7 years. Of the total participants, 4,745 (52.7%) were male students and 4,619 (51.3%) were urban children and adolescents. Comparing the group with low depression scores (CES-D<20) to the high depression score group (CES-D≥20), several significant distinguishing characteristics were found. Table 1 provides a detailed overview of these differences.

TABLE 1. Basic demographic characteristics of children sorted by CES-D scores.

Variable	CES-D (≥20), *n*=1,571	CES-D (<20), *n*=7,426	χ^2/*t*	*P*
Age*, years, mean±SD	14.8±1.6	14.3±1.7	9.67	<0.001
Male students*, *n* (%)	774 (49.3)	3,971 (53.5)	9.20	0.002
Urban, *n* (%)	803 (51.1)	3,816 (51.4)	0.04	0.844
Year*				
2017–2019	746 (18.6)	3,275 (81.4)	6.01	0.014
2020–2022	825 (16.6)	4,151 (79.1)		
Middle and high school grade*				
Grade 7	193 (10.9)	1,574 (89.1)	103.18	<0.001
Grade 8	267 (15.0)	1,514 (85.0)		
Grade 9	328 (18.9)	1,409 (81.1)		
Grade 10	249 (19.1)	1,055 (80.9)		
Grade 11	270 (21.4)	994 (78.6)		
Grade 12	264 (23.1)	880 (76.9)		
Resident students*, *n* (%)	393 (25.0)	1,573 (21.1)	11.16	<0.001
Single-parent household*, *n* (%)	133 (8.5)	499 (6.7)	6.05	0.014
BMI*, kg/m^2, mean±SD	22.2±4.2	21.7±4.1	4.23	<0.001
Passive smoking*, *n* (%)	169 (10.8)	354 (4.8)	84.99	<0.001
Sleep duration*, h	6.7±1.6	7.3±1.4	14.76	<0.001
Physical activity (≥2 h)*, *n* (%)	371 (23.6)	2,205 (29.7)	23.44	<0.001
Child growth development*, *n* (%)	1,266 (80.6)	5,334 (71.8)	50.88	<0.001
Vision*, mean±SD	4.3±0.4	4.4±0.4	8.00	<0.001
Healthy vision (≥5.0), *n* (%)	128 (8.1)	971 (13.1)	61.98	<0.001
Mild and moderate visual impairment (4.6–4.9), *n* (%)	263 (16.7)	1,397 (18.8)		
Severe vision impairment group 2 (4.0–4.5), *n* (%)	651 (41.4)	3,169 (42.7)		
Severe vision impairment group 1 (≤4.0), *n* (%)	529 (33.7)	1,889 (25.4)		

Abbreviation: CES-D=Center for Epidemiologic Studies Depression Scale; SD=standard deviation; BMI=body mass index.
* *P*<0.05.

We conducted a pooled analysis to examine the association between visual impairment and depressive symptoms. Three models were used: Model 1 with no covariates, Model 2 with covariates such as age, gender, region, and year, and Model 3 with a comprehensive set of covariates including age, gender, region, resident students, family type, BMI, passive smoking, sleep duration, physical activity, and child growth development, along with year. In Model 3, compared to the healthy vision group (visual acuity ≥5.0), the *OR*s for the severe vision impairment group 1 (≤4.0), severe vision impairment group 2 (visual acuity between 4.1 and 4.5), and mild and moderate visual impairment group (visual acuity between 4.6 and 4.9) were 1.90 (95% *CI*: 1.53–2.37), 1.53 (95% *CI*: 1.24–1.88), and 1.46 (95% *CI*: 1.16–1.84), respectively. These findings indicate a significant population-level association between vision impairment and depressive symptoms among Chinese students (Figure 2).

DISCUSSION

From 2017 to 2022, this study was conducted at 11 project sites involving a total of 8,997 middle and high school students. A pooled analysis was performed, adjusting for various covariates such as age, gender, region, residential status, family type (indicating single-parent household status), BMI, passive smoking, sleep duration, physical activity (evaluating if daily outdoor activity exceeded 2 hours), child growth development (referring to menstrual cycles or nocturnal emissions), and year. The analysis revealed a statistically significant association between the group with severe vision impairment and depressive symptoms compared to the group with healthy vision.

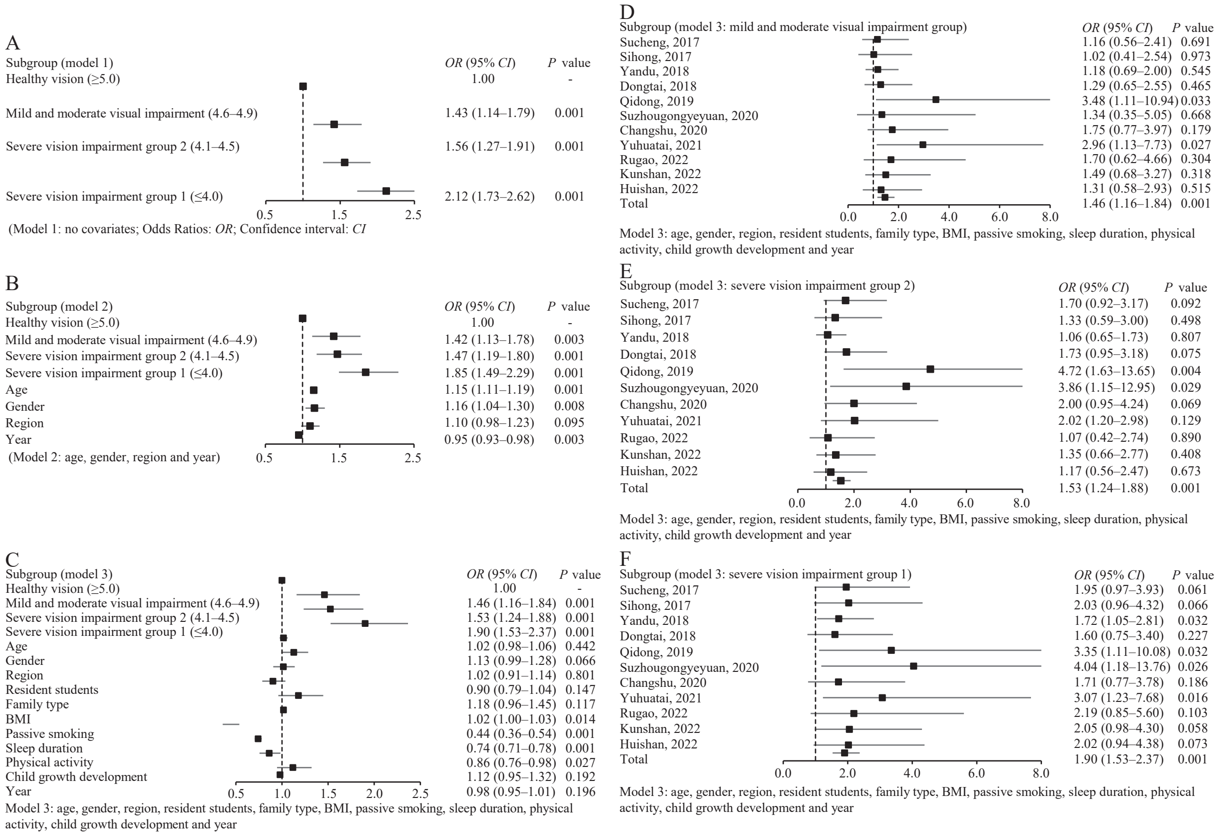

FIGURE 2. Forest plot depicting the association between visual impairment and depressive symptoms. (A) Relationship between visual impairment and depressive symptoms with Model 1; (B) relationship between visual impairment and depressive symptoms with Model 2; (C) relationship between visual impairment and depressive symptoms with Model 3; (D) relationship between visual impairment (4.6–4.9) and depressive symptoms with Model 3 sorted by regions; (E) relationship between visual impairment (4.1–4.5) and depressive symptoms with Model3 sorted by regions; (F) relationship between visual impairment (≤4.0) and depressive symptoms with Model 3 sorted by regions.
Abbreviation: *OR*=odds ratio; *CI*=confidence interval; BMI=body mass index.

The intricate neural mechanisms connecting vision and depression require a comprehensive investigation of various biological, psychological, and sociocultural factors. While previous studies have observed a statistical correlation between visual impairment and depression symptoms or other mental health concerns (*7–8*), caution is necessary when interpreting this association as it does not establish a cause-and-effect relationship. To gain a better understanding of this connection, further research, including long-term observational studies and examinations of potential mechanisms, is needed. The processing of visual information involves multiple brain regions, such as the visual cortex, secondary visual cortex, and emotionally-related areas like the amygdala (*9*). Abnormal processing of visual information or visual impairments may consequently impact the functioning of these brain regions and influence emotional states (*10*). Moreover, visual impairments can lead to social isolation, self-awareness issues, and daily life challenges, which may contribute to the onset of depressive symptoms (*11*).

This study is subject to some limitations. First, it would benefit from continued longitudinal follow-up with the population to explore causal relationships further. Long-term observation is essential for definitive establishment of causality. Second, reliance on self-reported data without clinical or objective measurements, particularly when assessing depression, introduces potential bias or inaccuracies due to personal perception and interpretation.

In conclusion, this six-year observational study found a significant association at the population level between visual impairment and symptoms of depression among school-age children. These findings highlight the importance of addressing both the visual and psychological well-being of students with compromised vision. The study provides valuable insights for interventions targeting the co-occurrence of visual and mental health conditions in students. Given the shared nature of common diseases in this population and their underlying mechanisms, a comprehensive approach to public health policies can offer invaluable guidance.

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Methods and Applications

Global Deaths Associated with Population Aging — 1990–2019

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ABSTRACT

Introduction: Published global and country-specific deaths associated with population aging are based on decomposition methods that have significant limitations.

Methods: A new decomposition method was developed and its performance was compared with two frequently used methods. The new method was employed to calculate global deaths associated with population aging between 1990 and 2019, using estimates from the Global Burden of Disease Study 2019 (GBD 2019).

Results: Compared to the two frequently-used existing methods, the new decomposition method generated results that are more consistent with logical expectations. Using the new method, the number of global deaths associated with population aging between 1990 and 2019 was 23.3 million. Upper middle-income countries accounted for 43% of global deaths related to population aging. The most deaths associated with population aging occurred from three types of disease: ischemic heart disease (5.0 million), stroke (3.8 million), and chronic obstructive pulmonary disease (2.2 million). China, India, Japan, the United States of America, and Brazil had the largest number of deaths related to population aging. Loss related to population aging was completely or partially counteracted by the reduction in mortality in 195 of the 200 countries and territories experiencing population aging (97.5%).

Conclusions: The new decomposition method achieves more justifiable results associated with population aging than existing methods. Globally, population aging was associated with a substantial increase of deaths between 1990 and 2019, but it was totally or partially offset by the reduction in mortality in 97.5% of countries and territories.

As the population ages steadily in most countries around the world, it has become an increasing research priority to quantify the deaths associated with population aging globally, nationally, and locally. All existing decomposition approaches use changes in age structure to approximate population aging (*1*–*3*). This method does not precisely measure deaths associated with population aging and becomes especially problematic in situations where the proportion of old adults increases but the number decreases, such as when conflicts or wars cause more deaths among young and middle-aged adults than among older adults. Recent situations in Iraq and Syria offer examples (*1*,*4*–*5*).

To address gaps in available research evidence caused by methodological limitations in existing decomposition methods, we developed a novel decomposition method. This new method was applied to data from the Global Burden of Disease Study 2019 (GBD 2019) to calculate the worldwide deaths related to population aging between 1990 and 2019. Additionally, we evaluated whether the benefits of improving population health through mortality reduction were greater than the health loss associated with population aging.

METHODS

Unlike previously published decomposition methods that approximate changes in age structure as population aging (*1*–*3*), the new method defines the increase in the number of old adults as population aging. Detailed derivation of the new decomposition method and a comparative evaluation of its performance versus two of the most-cited decomposition methods (number-based and rate-based methods) can be found in Supplementary Material (available in https://weekly.chinacdc.cn/). We chose the number-based method developed by Cheng et al. (*3*) as a comparator because it has clear advantages compared to alternatives. We also selected the widely-used rate-based decomposition method as the other comparator (*6*). Four countries, which experienced inconsistent changes in the number and proportion of old adults between 1990 and 2019, were selected to create four scenarios for comparing the performance across the three decomposition methods.

All data were derived from online resources of the GBD 2019, which provides estimates for multiple health outcomes across 369 diseases and injuries, and sex-specific population sizes for 204 countries and territories from 1990 to 2019. Detailed estimation methods for GBD 2019 appeared elsewhere (*7–8*).

Based on World Bank classifications, we categorized the 204 countries and territories into four income groups: low-income countries (LICs), lower middle-income countries (LMICs), upper middle-income countries (UMICs), and high-income countries (HICs). We conducted disease-specific analyses using the level-3 disease categorization (134 subcategories) defined by the GBD 2019. Populations were divided into 20 age groups, ranging from under 5 years to 95 years and older.

We utilized the novel decomposition method to compute global sex-, disease-, and country/territory-specific fatalities linked to population aging from 1990 to 2019. Bar charts and maps were utilized to visually depict subgroup disparities and geographic variances.

We examined the counteracting effect of reducing mortality rates in relation to population aging by using the ratio (denoted as *R*) of the number of deaths attributed to mortality reduction divided by that associated with population aging based on previous literature (*3*,*9*). As the numbers of deaths attributed to population aging and to reduced age-specific mortality are in opposite directions and sum to the net change in total deaths, *R* has a clear epidemiological interpretation in measuring the relative effect of mortality reduction and population aging. For the 200 out of 204 countries and territories that experienced population aging between 1990 and 2019, "$R \leq -1$", "$-1<R<0$" and "$R=0$" respectively suggest that the benefit achieved due to mortality reduction "clearly exceeded", "partially balances" or "does not alleviate" the loss associated with population aging. "$R>0$" indicates that the mortality increase exacerbates the loss associated with population aging.

All data analyses were performed using R4.2.2 (R Foundation, Vienna, Austria), and the package 'maps' was used to draw the maps. The study protocol was approved by the Ethics Committee of Xiangya School of Public Health, Central South University on 26 July 2022 (No. XYGW-2022-46).

RESULTS

Global deaths associated with population aging between 1990 and 2019 total approximately 23.3 million, with 12.0 million among men and 11.3 million among women (Figure 1A). UMICs have the largest number of deaths associated with population aging during 1990–2019, with 10.0 million, followed by LMICs (7.0 million), HICs (5.5 million), and LICs (0.8 million) (Figure 1B).

The number of deaths associated with population aging vary greatly across different types of diseases between 1990 and 2019 (Figure 1C). The top ten causes of disease accounted for a total of 16.1 million global deaths related to population aging (69.2%); these included ischemic heart disease (5.0 million); stroke (3.8 million); chronic obstructive pulmonary disease (COPD, 2.2 million); Alzheimer's disease and other dementias (ADOD, 1.0 million); lower respiratory infections (1.0 million); tracheal, bronchus, and lung (TBL) cancer (0.8 million); diarrheal diseases (0.7 million); hypertensive heart disease (0.6 million); diabetes mellitus (0.6 million); and chronic kidney disease (0.5 million).

Of the 200 countries and territories that experienced population aging between 1990 and 2019, the number of deaths associated with population aging varied substantially across countries and territories. China, India, Japan, the United States, and Brazil had the largest number of deaths related to population aging and together accounted for 58.8% of global decomposed deaths. Respective numbers of deaths in those five countries were 6.4 million, 4.4 million, 1.1 million, 1.0 million, and 0.7 million.

Between 1990 and 2019, the number of global deaths averted by reductions in mortality exceeded those associated with population aging (−23.5 million *vs*. 23.3 million) (Figure 2A). Subgroup analyses show that the decrease in deaths due to mortality reduction completely offsets the increase associated with population aging among males (−12.5 million *vs*. 12.0 million) and in both LMICs (−8.9 million *vs*. 7.0 million) and LICs (−3.1 million *vs*. 0.8 million), but the counteracting effect is only partial in UMICs (−7.8 million *vs*. 10.0 million) and HICs (−3.6 million *vs*. 5.5 million) (Figure 2B).

Among the top ten diseases with the highest mortality rates associated with population aging, the counteracting effect of reduced mortality is most pronounced for lower respiratory infections (−2.1 million *vs*. 0.96 million) and diarrheal diseases (−2.3

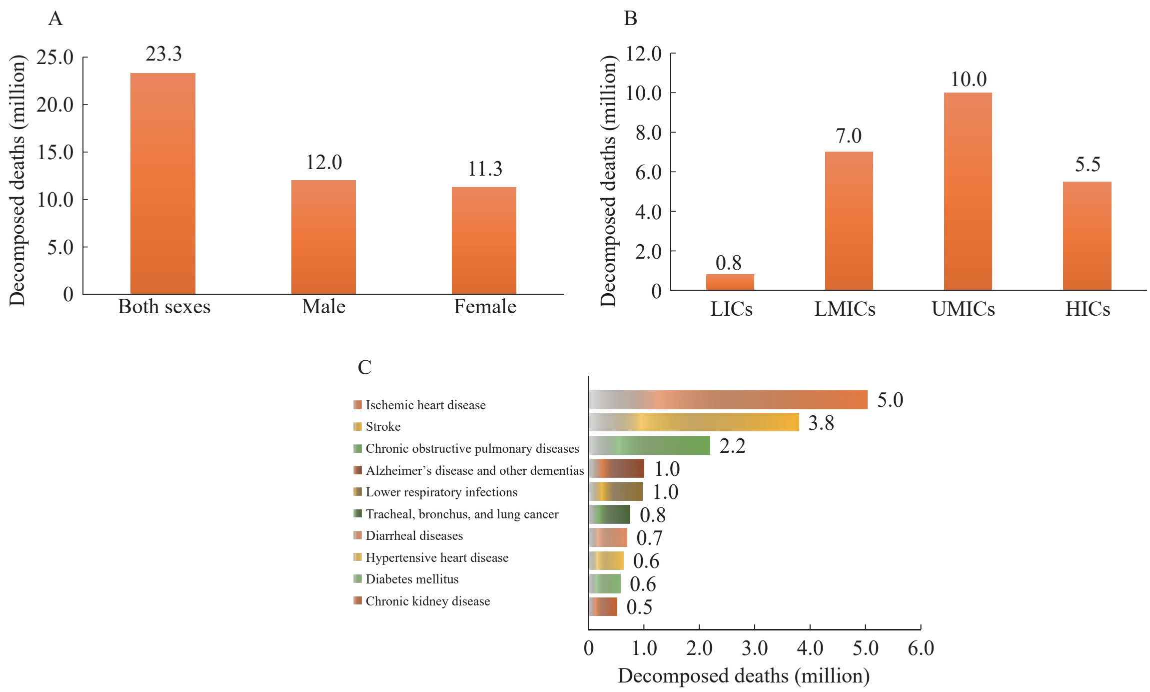

FIGURE 1. Global deaths related to population aging between 1990 and 2019 by (A) sex; (B) country income; (C) type of dise.

Abbreviation: LICs=low-income countries; LMICs=lower middle-income countries; UMICs=upper middle-income countries; HICs=high-income countries.

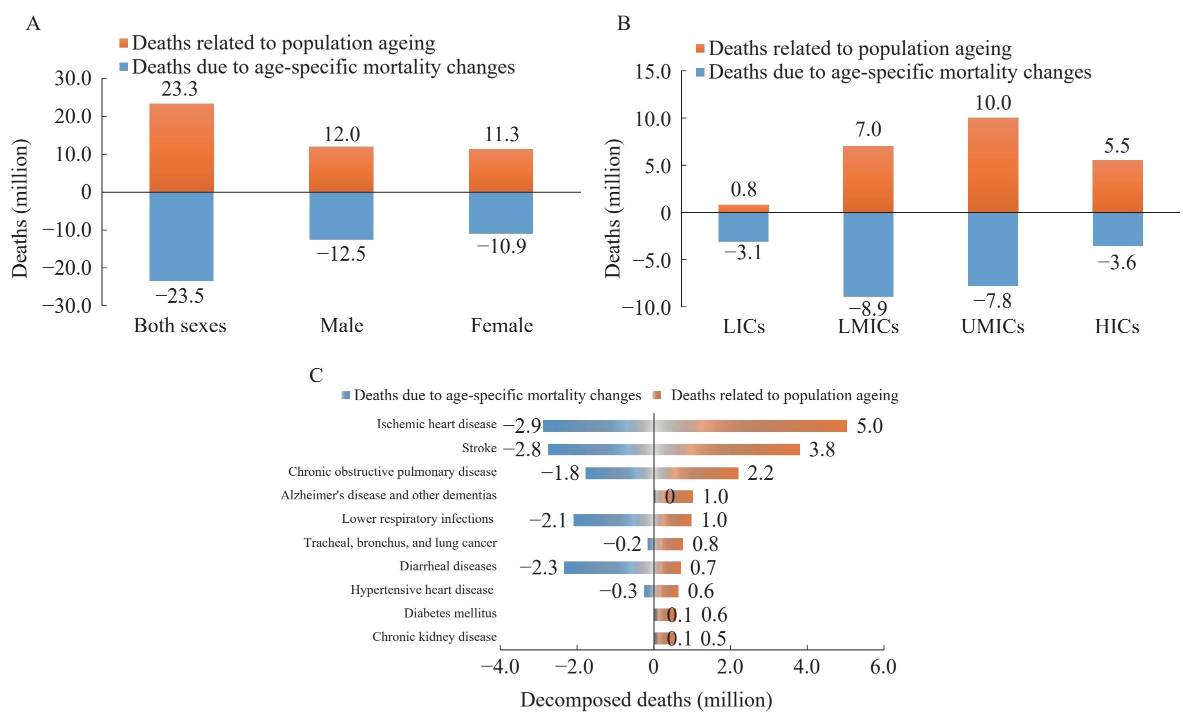

FIGURE 2. The counteracting effect of mortality reduction against the loss related to population aging between 1990 and 2019. (A) by sex; (B) by country income; (C) by type of disease.

million *vs*. 0.7 million) (Figure 2C). The reduction in mortality was insufficient to counteract the effects of population aging for five disease types: ischemic heart disease (−2.9 million *vs*. 5.0 million); stroke (−2.8

million *vs.* 3.8 million); COPD (−1.8 million *vs.* 2.2 million); TBL cancer (−0.2 million *vs.* 0.8 million); and hypertensive heart disease (−0.3 million *vs.* 0.6 million). Importantly, the increase in mortality intensified the impact of population aging on three disease types: ADOD (0.03 million *vs.* 1.0 million), diabetes mellitus (0.08 million *vs.* 0.6 million), and chronic kidney disease (0.1 million *vs.* 0.5 million).

Of the 200 countries and territories that experienced population aging between 1990 and 2019, the health loss associated with population aging was outweighed by the benefits from mortality reduction in 44.0% (88 of 200 countries/territories, $R \leq -1$), and was partially counteracted in 53.5% (107 of 200, $-1 < R \leq 0$). The most notable counteracting effect occurred in Tajikistan, with an R of −40.8. In contrast, the health loss related to population aging was not offset at all in five countries (5 of 200, $R > 0$): Lesotho, Eswatini, Zimbabwe, Montenegro, and Ukraine.

DISCUSSION

This study presents two main findings. First, the new decomposition method produced decomposed results that align more closely with logical expectations compared to traditional decomposition methods, estimating a total of 23.3 million deaths associated with global population aging. Second, the number of deaths related to population aging was completely or partially offset by the lives saved as a result of mortality reduction in 195 out of the 200 countries and territories with aging population between 1990 and 2019.

The new decomposition method produces more reliable estimates that align with logical expectations compared to the two most cited methods, as supported by both its theoretical foundation and data illustration (Supplementary Material and Supplementary Table S1, available in https://weekly.chinacdc.cn/). First, it employs the number of elderly individuals to measure population aging, whereas existing decomposition methods use changes in the age structure as a proxy of population aging. This proxy does not accurately reflect the impact of population aging in certain situations, and it can lead to misleading decomposed results. Second, it equally separates the interaction of age-specific population size and age-specific rate, ensuring the robustness of the results regardless of the decomposition order of these two factors, as outlined in the Supplementary Materials.

A total of 23.3 million deaths associated with population aging reflects the significant impact of population aging on our society. Substantial differences in the number of deaths associated with population aging across sex, country/territory, country income level, and type of disease generally reflect the combined effects of varying demographics and disparities in socio-economic development. The former is related to the steady rise of older adults due to reduced birth rate and prolonged life expectancy in many countries, while the latter country/territory differences are attributed to variations in economic development, migration, education, and healthcare services (*10*). For instance, the United States accounted for 23.9% of the global gross domestic product (GDP) (*11*), but only 4.7% of the global deaths associated with population aging.

Despite the alarming 23.3 million global deaths associated with population aging, our findings also demonstrate that the lives saved due to mortality reduction have completely or partially offset the increased deaths associated with population aging between 1990 and 2019 in almost all countries and territories (195 of 200). However, the counteracting effect of mortality reduction varied across subgroups. Specifically, overall mortality increased in five countries (Lesotho, Eswatini, Zimbabwe, Montenegro, and Ukraine) between 1990 and 2019, exacerbating deaths associated with population aging. These findings highlighted the importance and urgency of reducing mortality disparities across countries and territories.

Our findings have at least three important policy implications. First, we recommend the use of the new decomposition method to calculate health outcome counts associated with population aging. Second, our findings highlight the importance and urgency of taking prevention and control actions to curb the large loss of life related to population aging globally and nationally. Field-proven and cost-effective prevention measures, along with medical treatments for high-mortality diseases among the elderly, should be prioritized and implemented worldwide. Third, globally coordinated efforts and investments should be undertaken to reduce disparities in morbidity and mortality associated with population aging across countries and territories.

This study is primarily limited by the availability and quality of estimates from the GBD 2019 public database. In addition, due to the unavailability of complete data on mortality rates, we are unable to provide 95% uncertainty intervals for our estimates. These limitations could be addressed by including high-quality raw data and methodological innovations in future research.

CONCLUSION

The new method we developed is robust and consistent with logical expectations in calculating deaths associated with population aging compared to the two most cited decomposition methods. Therefore, we recommend researchers and policymakers to use the new decomposition method to calculate deaths (and other health losses) associated with population aging. We also call for coordinated global efforts to address the challenge of population aging, which should include prioritization of preventing and treating leading types of disease, implementation of empirically-supported and cost-effective prevention and treatment measures worldwide, and distribution of international aid to support the most affected countries and territories.

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SUPPLEMENTARY MATERIAL

Description of the New Decomposition Method

Suppose that we have collected the following aggregate data for 20 age groups in a given country from the two years over a two-year period: age-specific population size (n_{ij}) and age-specific mortality rate (r_{ij}), $i = 1, 2$ indexing the year and $j = 1, 2, \cdots, 20$ indexing the age groups. The total population sizes and overall mortality rates in the country over the two years are accordingly calculated as $N_1 = \sum_{j=1}^{20} n_{1j}$, $N_2 = \sum_{j=1}^{20} n_{2j}$, $R_1 = \frac{1}{N_1}\sum_{j=1}^{20} n_{1j} \times r_{1j}$, and $R_2 = \frac{1}{N_2}\sum_{j=1}^{20} n_{2j} \times r_{2j}$. D_1 and D_2 represent the total number of deaths in the given country in years 1 and 2.

$$D_2 - D_1 = \sum_{j=1}^{20} n_{2j}r_{2j} - \sum_{j=1}^{20} n_{1j}r_{1j} = M_n + M_r + I_{n\times r} \tag{1}$$

Where M_n, M_r, and $I_{n\times r}$ denote the main effect of changes in age-specific population size, age-specific mortality, and their interaction.

With the use of the following formulas, we are able to calculate the number of deaths associated with population aging during a specific time frame.

First, calculate the values of M_n, M_r, and $I_{n\times r}$ using the following formulas:

$$M_n = \sum_{j=1}^{20} \left(n_{2j} - n_{1j}\right) r_{1j} \tag{2}$$

$$M_r = \sum_{j=1}^{20} n_{1j} \left(r_{2j} - r_{1j}\right) \tag{3}$$

$$I_{n\times r} = \sum_{j=1}^{20} \left(n_{2j} - n_{1j}\right)\left(r_{2j} - r_{1j}\right) \tag{4}$$

Second, separate the main effects and interactions related to older adults from M_n, M_r, and $I_{n\times r}$. According to the operational definition of older adults (≥65 years), we can divide each of M_n, M_r, and $I_{n\times r}$ into two parts, for those younger than 65 years old and those ≥65 years old. Let a represent the age group of 65 to 70 years old, and we can rewrite the formulas of M_n, M_r, and $I_{n\times r}$ as follows:

$$M_n = M_{n,<65\text{years}} + M_{n,\geq 65\text{years}} = \sum_{j=1}^{a-1} \left(n_{2j} - n_{1j}\right) r_{1j} + \sum_{j=a}^{20} \left(n_{2j} - n_{1j}\right) r_{1j} \tag{5}$$

SUPPLEMENTARY TABLE S1. Deaths and mortality associated with population aging between 1990 and 2019 in four selected countries based on the three decomposition methods.*

Country	Number of old adults aged ≥65			Proportion of old adults aged ≥65 (%)			Deaths/mortality related to aging†		
	1990	2019	Change	1990	2019	Change	Method Ⅰ	Method Ⅱ§	Method Ⅲ
Afghanistan	560,091	784,021	223,930	4.9	2.1	−2.8	−77,227	−315	20,800
China	65,625,721	178,348,576	112,722,855	5.5	12.5	7.0	6,529,541	504	6,429,286
Nauru	188	168	−20	1.8	1.6	−0.2	0¶	2	−3
Niue	203	186	−17	8.7	11.1	2.4	5	237	−2

* To properly compare three decomposition methods, we followed the basic guideline that a valid method should reflect the impact of population aging in a reasonable direction. Specifically, a valid decomposition method should generate an increase (decrease) in aging-associated health outcome counts or rates as the population ages (gets younger), according to common logic that older adults typically have higher all-cause mortality and morbidity rates than children and younger adults.

† Methods Ⅰ and Ⅱ respectively denote the commonly used number-based and rate-based decomposition methods (*1*,*5*,*6*). Method Ⅲ represents the new decomposition method;

§ Decomposed results of methods Ⅰ and III are reported in the number of deaths, and decomposed results of method II are reported as mortality per 100,000 persons;

¶ The decomposed deaths of method I was 0.18 for Nauru due to the small population size and was therefore rounded to zero.

$$M_r = M_{r,<65\text{years}} + M_{r,\geq 65\text{years}} = \sum_{j=1}^{a-1} n_{1j}\left(r_{2j} - r_{1j}\right) + \sum_{i=a}^{20} n_{1j}\left(r_{2j} - r_{1j}\right) \tag{6}$$

$$I_{n\times r} = I_{n\times r,<65\text{years}} + I_{n\times r,\geq 65\text{years}} = \sum_{j=1}^{a-1}\left(n_{2j} - n_{1j}\right)\left(r_{2j} - r_{1j}\right) + \sum_{j=a}^{20}\left(n_{2j} - n_{1j}\right)\left(r_{2j} - r_{1j}\right) \tag{7}$$

Third, calculate the deaths associated with population aging between the two years. We need to first allocate the interaction reasonably and then calculate the health loss associated with population aging.

(a) Justification of interaction allocation

Based on Formulas (2–4), we assume that the proportion of allocating the interaction is Φ in our decomposition method. Therefore, the deaths associated with population aging between years 1 and 2 (PA) are:

$$PA = M_{n,\geq 65\text{years}} + \Phi I_{n\times r,\geq 65\text{years}} = \sum_{j=a}^{20}\left[\left(n_{2j} - n_{1j}\right) r_{1j} + \Phi(n_{2j} - n_{1j})(r_{2j} - r_{1j})\right] \tag{8}$$

When the reference population is changed from population 1 to population 2, the deaths associated with population aging between years 1 and 2 ($PA_a^{,}$) is:

$$PA' = \sum_{j=a}^{20}\left[\left(n_{1j} - n_{2j}\right) r_{2j} + \Phi(n_{1j} - n_{2j})(r_{1j} - r_{2j})\right] \tag{9}$$

To ensure the robustness of decomposed results, we restrict PA to be equal to -PA'. Under this restriction, Formulas (8) and (9) lead to:

$$\sum_{j=a}^{20}\left(n_{2j} - n_{1j}\right) r_{1j} + \Phi\sum_{j=a}^{20}\left(n_{2j} - n_{1j}\right)\left(r_{2j} - r_{1j}\right) = \sum_{j=a}^{20}\left(n_{2j} - n_{1j}\right) r_{2j} - \Phi\sum_{j=a}^{20}(n_{2j} - n_{1j})(r_{2j} - r_{1j}) \tag{10}$$

which implies Φ= 1/2.

(b) Calculate health loss associated with population aging

Based on the equal allocation of interaction, we use Formula (11) to estimate the health loss associated with population aging (PA):

$$PA = M_{n,\geq 65\text{years}} + 1/2 I_{n\times r,\geq 65\text{years}} \tag{11}$$

Calculation of Subgroup Decomposition Analysis

We demonstrate the application of sex-specific decomposition using the following example. The number of deaths and populations can be aggregated separately for each sex. According to Formula (8), we can compute the number of deaths associated with population aging for the entire population, as well as for males and females, denoted as $\text{PA}_{\text{overall}}$, PA_{male}, and $\text{PA}_{\text{female}}$:

$$\begin{aligned} PA_{\text{overall}} &= \sum_{j=a}^{20}\left(n_{2j} - n_{1j}\right) r_{1j} + 1/2\sum_{j=a}^{20}\left(n_{2j} - n_{1j}\right)\left(r_{2j} - r_{1j}\right) \text{PA} = M_{n,\geq 65\text{years}} + 1/2 I_{n\times \text{r},\geq 65\text{years}} \\ &= \sum_{j=a}^{20}\left[\left(n_{2j,\text{m}} + n_{2j,\text{f}}\right) - \left(n_{1j,\text{m}} + n_{1j,\text{f}}\right)\right] r_{1j} + 1/2\sum_{j=a}^{20}\left[\left(n_{2j,\text{m}} + n_{2j,\text{f}}\right) - \left(n_{1j,\text{m}} + n_{1j,\text{f}}\right)\right]\left(r_{2j} - r_{1j}\right) \end{aligned} \tag{12}$$

$$PA_{\text{male}} = \sum_{j=a}^{20}\left(n_{2j,\text{m}} - n_{1j,\text{m}}\right) r_{1j,\text{m}} + 1/2\sum_{j=a}^{20}\left(n_{2j,\text{m}} - n_{1j,\text{m}}\right)\left(r_{2j,\text{m}} - r_{1j,\text{m}}\right) \tag{13}$$

$$PA_{\text{female}} = \sum_{j=a}^{20}\left(n_{2j,\text{f}} - n_{1j,\text{f}}\right) r_{1j,\text{f}} + 1/2\sum_{j=a}^{20}\left(n_{2j,\text{f}} - n_{1j,\text{f}}\right)\left(r_{2j,\text{f}} - r_{1j,\text{f}}\right) \tag{14}$$

Because generally $r_{1j} \neq r_{1j,\text{m}} \neq r_{1j,\text{f}}$ and $r_{2j} \neq r_{2j,\text{m}} \neq r_{2j,\text{f}}$, PA_{overall} does not necessarily equal the sum of PA_{male} and PA_{female}. This conflicts with the common expectation that the overall decomposed result should equal the sum of subgroup decomposed results for males and females.

We further investigated under what conditions $PA_{\text{overall}} = (PA_{\text{male}} + PA_{\text{female}})$ does hold. Assume $q_{ij} = n_{ij,\text{m}}/n_{ij}$

denotes the proportion of males in age group j at time point i. We then have $r_{ij} = \left(n_{ij,\mathrm{m}} r_{ij,\mathrm{m}} + n_{ij,\mathrm{f}} r_{ij,\mathrm{f}}\right) / n_{ij} = q_{ij} r_{ij,\mathrm{m}} + (1 - q_{ij}) r_{ij,\mathrm{f}}$. Using Formulas (12–14), we get

$$
\begin{aligned}
G &= PA_{\mathrm{overall}} - (PA_{\mathrm{male}} + PA_{\mathrm{female}}) \\
&= \sum_{j=a}^{20} \left[\left(n_{2j,\mathrm{m}} - n_{1j,\mathrm{m}}\right)\left(r_{1j} - r_{1j,\mathrm{m}}\right) + \left(n_{2j,\mathrm{f}} - n_{1j,\mathrm{f}}\right)\left(r_{1j} - r_{1j,\mathrm{f}}\right)\right] + \frac{1}{2}\sum_{j=a}^{20}\left(n_{2j,\mathrm{m}} - n_{1j,\mathrm{m}}\right)\left[\left(r_{2j} - r_{1j}\right) - \left(r_{2j,m} - r_{1j,m}\right)\right] \\
&\quad + \frac{1}{2}\sum_{j=a}^{20}\left(n_{2j,\mathrm{f}} - n_{1j,\mathrm{f}}\right)\left[\left(r_{2j} - r_{1j}\right) - \left(r_{2j,f} - r_{1j,f}\right)\right] \\
&= \frac{1}{2}\sum_{j=a}^{20}\left(n_{2j,\mathrm{m}} - n_{1j,\mathrm{m}}\right)\left(r_{1j} - r_{1j,\mathrm{m}}\right) + \frac{1}{2}\sum_{j=a}^{20}\left(n_{2j,\mathrm{f}} - n_{1j,\mathrm{f}}\right)\left(r_{1j} - r_{1j,\mathrm{f}}\right) \\
&\quad + \frac{1}{2}\sum_{j=a}^{20}\left(n_{2j,\mathrm{m}} - n_{1j,\mathrm{m}}\right)\left(r_{2j} - r_{2j,m}\right) + \frac{1}{2}\sum_{j=a}^{20}\left(n_{2j,\mathrm{f}} - n_{1j,\mathrm{f}}\right)\left(r_{2j} - r_{2j,f}\right) \\
&= \frac{1}{2}\sum_{j=a}^{20}\left(n_{2j,\mathrm{m}} - n_{1j,\mathrm{m}}\right)\left(r_{1j} + r_{2j} - r_{1j,m} - r_{2j,\mathrm{m}}\right) + \frac{1}{2}\sum_{j=a}^{20}\left(n_{2j,\mathrm{f}} - n_{1j,\mathrm{f}}\right)\left(r_{1j} + r_{2j} - r_{1j,f} - r_{2j,\mathrm{f}}\right) \\
&= \frac{1}{2}\sum_{j=a}^{20}\left(n_{2j}q_{2j} - n_{1j}q_{1j}\right)\left[q_{1j}r_{1j,\mathrm{m}} + \left(1 - q_{1j}\right)r_{1j,\mathrm{f}} + q_{2j}r_{2j,\mathrm{m}} + \left(1 - q_{2j}\right)r_{2j,\mathrm{f}} - r_{1j,m} - r_{2j,\mathrm{m}}\right] + \\
&\quad \frac{1}{2}\sum_{j=a}^{20}\left[n_{2j}\left(1 - q_{2j}\right) - n_{1j}\left(1 - q_{1j}\right)\right]\left(q_{1j}r_{1j,\mathrm{m}} + \left(1 - q_{1j}\right)r_{1j,\mathrm{f}} + q_{2j}r_{2j,\mathrm{m}} + \left(1 - q_{2j}\right)r_{2j,\mathrm{f}} - r_{1j,f} - r_{2j,\mathrm{f}}\right) \\
&= \frac{1}{2}\sum_{j=a}^{20}\left(n_{2j}q_{2j} - n_{1j}q_{1j}\right)\left[(1 - q_{1j})\left(r_{1j,\mathrm{f}} - r_{1j,\mathrm{m}}\right) + (1 - q_{2j})\left(r_{2j,\mathrm{f}} - r_{2j,\mathrm{m}}\right)\right] + \\
&\quad \frac{1}{2}\sum_{j=a}^{20}\left[n_{2j}(1 - q_{2j}) - n_{1j}(1 - q_{1j})\right]\left[q_{1j}\left(r_{1j,\mathrm{m}} - r_{1j,f}\right) + q_{2j}\left(r_{2j,\mathrm{m}} - r_{2j,\mathrm{f}}\right)\right]
\end{aligned}
$$

Under the assumption that age-specific sex ratios do not change between time points 1 and 2 (i.e., $q_{1j} = q_{2j}$), the above expression can be simplified as

$$
\begin{aligned}
G &= PA_{\mathrm{overall}} - (PA_{\mathrm{male}} + PA_{\mathrm{female}}) = \frac{1}{2}\sum_{j=a}^{20} q_j\left(1 - q_j\right)\left(n_{2j} - n_{1j}\right)\left[\left(r_{1j,\mathrm{f}} + r_{2j,\mathrm{f}}\right) - \left(r_{1j,\mathrm{m}} + r_{2j,\mathrm{m}}\right)\right] - \\
&\quad \frac{1}{2}\sum_{j=a}^{20} q_j\left(1 - q_j\right)\left(n_{2j} - n_{1j}\right)\left[\left(r_{1j,f} + r_{2j,\mathrm{f}}\right) - \left(r_{1j,\mathrm{m}} + r_{2j,\mathrm{m}}\right)\right] = 0
\end{aligned}
$$

That is, $PA_{\mathrm{overall}} = (PA_{\mathrm{male}} + PA_{\mathrm{female}})$ holds under this assumption.

When the age-specific sex ratio changes over time (i.e., $q_{1j} \neq q_{2j}$), the gap (G) between PA_{overall} and ($PA_{\mathrm{male}} + PA_{\mathrm{female}}$) does not necessarily equal zero in all cases. To ensure $PA_{\mathrm{overall}} = (PA_{\mathrm{male}} + PA_{\mathrm{female}})$ and to maintain the comparative contribution of subgroup decomposed results, we adopt a simple proportional allocation method to distribute the gap (G) between PA_{overall} and $PA_{\mathrm{male}} + PA_{\mathrm{female}}$ according to the contributions of subgroup decomposed results.

Specifically, we obtain the adjusted estimates of PA'_{male} and PA'_{female}:

$$G = PA_{\mathrm{overall}} - (PA_{\mathrm{male}} + PA_{\mathrm{female}}) \tag{15}$$

$$PA'_{\mathrm{male}} = PA_{\mathrm{male}} + G\left(\frac{PA_{\mathrm{male}}}{PA_{\mathrm{male}} + PA_{\mathrm{female}}}\right) \tag{16}$$

$$PA'_{\mathrm{female}} = PA_{\mathrm{female}} + G\left(\frac{PA_{\mathrm{female}}}{PA_{\mathrm{male}} + PA_{\mathrm{female}}}\right) \tag{17}$$

So that we ensure $PA_{\mathrm{overall}} = (PA'_{\mathrm{male}} + PA'_{\mathrm{female}})$ in all cases. Similarly, we calculate the adjusted contribution associated with population aging by other variables (i.e., type of disease, country/territory).

Performance of the New Decomposition Method

All existing decomposition methods can be divided into two categories according to the type of health metric to be decomposed: number-based and rate-based decomposition methods. We selected the number-based method developed by Cheng et al. (*1*) which was reported to have clear advantages compared to other number-based methods as a comparator, and the only rate-based decomposition method was selected as the other comparator. Compared to the two most cited methods (abbreviated as method I and method Ⅱ) (*1–2*), we assessed the performance of the new decomposition method (denoted as method Ⅲ). Compared to the two most frequently cited methods (abbreviated as method I and method Ⅱ) (*1–2*), we assessed the performance of the new decomposition method (denoted as method Ⅲ).

We selected four countries (Afghanistan, China, Nauru, and Niue) with varying changes the number and proportion of older adults between 1990 and 2019 to illustrate the comparative performance of the three methods. We followed a basic principle in comparing the performance of the three decomposition methods, which states that a valid method should reflect the impact of population aging in a reasonable manner. Specifically, a valid decomposition method should increase (decrease) in counts or rates of health outcomes associated with aging as the population ages (gets younger). This is based on the common understanding that older adults generally have higher rates of all-cause mortality and morbidity compared to children and younger adults.

We selected four countries that showed varying changes in the number of older adults and in the proportion of older adults (Supplementary Table S1). In both Afghanistan and China, the number of older adults aged 65 years and older increased between 1990 and 2019. However, the proportion of older adults aged 65 years and older decreased by 2.8% in Afghanistan but increased 7.0% in China. Nauru and Niue, two Pacific Island nations, showed different patterns. In both Nauru and Niue, the number of older adults decreased but the proportion of older adults decreased by 0.2% in Nauru and increased by 2.4% in Niue.

We expect a valid decomposition method to capture the increase of decomposition deaths (mortality) associated with population aging in both China and Afghanistan, as well as the decrease in decomposition deaths (mortality) associated with population aging in Niue and Nauru. As shown in Supplementary Table S1, only method III attained decomposed results associated with population aging in the correct direction for all four countries, with increases for Afghanistan and China, and decreases for Nauru and Niue. Methods I and II generated decomposed results deviating from expectations in Afghanistan, Nauru, and Niue.

Compared to other frequently used decomposition methods (*1–2*), the new decomposition method has two advantages. First, it generates reasonable decomposition results in all cases, overcoming deficiencies of existing methods such as being sensitive to the decomposition order of factors (*3–4*). Second, it relies on changes in the number of older adults rather than changes in age structure of the population. In this way, it more rationally captures the health effects of population aging and provides a more helpful basis for evaluating related health policies.

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