Temporal trends and patterns in mortality from falls across 59 high-income and upper-middle-income countries, 1990–2021, with projections up to 2040: a global time-series analysis and modelling study

Sunyoung Kim*, Soeun Kim*, Selin Woo, Jiyeon Oh, Yejun Son, Louis Jacob, Pinar Soysal, Jungha Park, Liang-Kung Chen, Dong Keon Yon

Summary

Background Deaths related to falls are a substantial public health problem worldwide, and insight into trends and differences in global fall-related deaths can be valuable for identifying prevention strategies and developing effective policies. Thus, we aimed to estimate global fall-related mortality rate trends and forecast future fall-related deaths.

Methods In this global time-series analysis and modelling study, we investigated temporal trends in fall-related mortality rates from 1990 to 2021 using the WHO Mortality Database, following the GATHER guidelines, and forecasted trends until 2040 across 59 high-income and upper-middle-income countries. We focused on identifying specific patterns of variation in mortality rates across different age groups, sexes, and income levels based on World Bank country classification. We analysed temporal trends and patterns using a locally weighted scatter plot smoother curve presented by age-standardised mortality rates (ASMRs), and future projections were calculated based on Bayesian age–period–cohort analysis. We performed a decomposition analysis to identify variations in fall-related deaths by examining factors such as population growth, ageing, and epidemiological changes.

Findings Fall-related mortality rates per 100 000 people declined from 23·21 (95% CI 21·30 to 25·12) in 1990 to 11·01 (9·94 to 12·08) in 2009, increasing to 12·50 (10·36 to 14·64) by 2021. Throughout the period from 1990 to 2021, fall-related mortality rates were consistently higher among men, individuals in high-income countries, and older adults. The results represent a clear pattern in fall-related mortality rates according to sex, income level, and age group. ASMRs exhibited varying patterns, with an initial decrease of 43·83% (from 11·54 [95% CI 9·33 to 13·76] in 1990 to 6·48 [95% CI 5·28 to 7·68] in 2005) in upper-middle-income countries with a subsequent rise of 49·69% to 9·70 (9·33 to 13·76) in 2021, with a 17·81% increase among women (from 9·04 in 2009 to 10·65 in 2021), and with a 1434·8% increase in individuals aged 85 years and older (from 5·00 [–4·94 to 14·94] in 1992 to 76·74 [62·10 to 91·39] in 2021). Furthermore, ASMRs showed a positive correlation with Socio-demographic Index (β=42·29 [10·26 to 74·32]; p<0·011), the Environmental Performance Index (β=0·19 [0·05 to 0·33]; p=0·0090), and the reverse Gini coefficient (β=22·58 [0·45 to 44·72]; p=0·046). Projections indicate that the fall-related mortality rate is expected to rise from 14·80 (95% credible intervals, 14·04 to 15·59) per 100 000 people in 2021 to 19·48 (7·02 to 98·84) by 2040. The increase in fall-related deaths from 1990 to 2040 can be attributed to the growth in population, because the absolute number of fall-related deaths has risen despite a declining rate.

Interpretation Temporal trend in fall-related deaths declined from 1990 to 2009, followed by an increase in 2021. Fall-related deaths among women and individuals aged 85 years and older will continue to increase until 2040, particularly in upper-middle-income countries. Urgent and proactive implementation of targeted interventions and prevention programmes is necessary to reduce fall-related mortality effectively.

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Introduction

A fall is defined as an unexpected event in which an individual comes to rest on the ground, floor, or lower level.[1] Falls are a leading global health challenge, ranking as the second cause of death from unintentional injuries.[2] Over 80% of these fatalities occur in low-income and middle-income countries, with the highest mortality rates observed among individuals aged 60 years and older.[3] WHO emphasises environmental and health-related gaps contributing to fall-related mortality, such as limited access to the health-care system and inadequate infrastructure.[2] However, the implementation of fall prevention strategies in low-income countries (LICs) and some middle-income countries (MICs) is often hindered by challenges such as data scarcity, inadequate health-care infrastructure, and limited resources.[2] In contrast, several high-income countries

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Research in context

Evidence before this study

The temporal trends and future projections of fall mortality are crucial to providing policy decision makers with insights into estimating the global and future burden of fall mortality; however, it requires techniques accounting for the effects of age, period, and cohort on trends in fall mortality and considering various factors, including population growth and ageing. On June 20, 2024, we searched PubMed for temporal trends or future projections of fall-related mortality by following the terms "accidental falls"[MeSH Terms] AND ("mortality"[MeSH Terms] OR "death"[MeSH Terms]) AND ("forecasting"[MeSH Terms] OR (("forecasting"[MeSH Terms] OR "forecasting"[All Fields] OR "future"[All Fields] OR "futures"[All Fields]) AND ("projection"[MeSH Terms] OR "forecasting"[MeSH Terms]))). We then systematically collected and reviewed papers on the temporal trends or future fall-related mortality projections. A previous study using Global Burden of Disease Study (GBD) data reported a 3·7% decrease in global fall-related mortality from 1990 to 2017. However, several restrictions apply when using the GBD dataset, such as reliance on meta-analysis, lack of original data, and estimation methods to compensate for missing data. Additionally, very few studies estimate future projections of fall-related mortality at global levels, and the results of several studies have been inconsistent, leading to doubts.

Added value of this study

We aimed to estimate the temporal trends in fall-related mortality rates from 1990 to 2021 and project future fall-related deaths until 2040 across 59 high-income and upper-middle-income countries. The age-standardised fall-related mortality rate decreased between 1990 and 2009 but increased to 2021. Furthermore, projections indicate that fall-related deaths are expected to rise globally by 2040, particularly among older adults, individuals with reduced intrinsic capacity, and populations in upper-middle-income countries experiencing health-care and resource constraints.

Implications of all the available evidence

These findings underscore the urgent need for more effective strategies and policies to address and reduce fall-related mortality on a global scale.

See Online for appendix

(HICs) such as Denmark, Switzerland, and Austria found persistently low or even declining rates of fall-related mortality, despite an ageing population.[4] Investigating the underlying factors contributing to these trends in HICs is crucial, as it not only provides valuable insights into effective prevention strategies but also serves as a basis for adapting such approaches to resource-constrained settings like LICs and MICs.

Although several studies have previously reported global fall-related mortality rates, these studies used data from national databases, such as the Global Burden of Disease Study (GBD), which provide publicly accessible data for researchers.[4,5] However, previous studies using this method lack sophistication in analysing fall-related deaths and trends, particularly in terms of accounting for geographical and socioeconomic disparities. Furthermore, predictions of future fall deaths that incorporate these disparities remain unclear.

The WHO Mortality Database includes medically certified deaths coded with ICD standards, ensuring reliability.[6] We aimed to use this database to elucidate the temporal trends in fall-related mortality rates and estimate the future burden of fall-related mortality across 59 countries up to 2040.

Methods

Study design

In this global time-series analysis and modelling study, we analysed trends in fall-related mortality in HICs and upper-middle-income countries (UMICs), based on the World Bank country classification, from 1990 to 2021 using data from the WHO Mortality Database following the GATHER statement (appendix pp 4–5). We projected future trends up to 2040 to examine the relationship between fall-related mortality and socioeconomic and geographical factors. The study protocol was approved by the Institutional Review Board of Kyung Hee University (KHSIRB-23-085).

Data sources

The primary data source for our study was the WHO Mortality Database, which compiles annual mortality data by age, sex, and cause of death as reported by WHO member states through their civil registration systems.[6] We extracted the number of fall-related deaths for all available countries, sexes, and age groups from 1990 to 2021. Countries with data from at least 26 of the 32 years studied within the observation period (1990–2021) were included. Each country's data reported to WHO were unadjusted absolute numbers, including zeros, with no imputation applied for unreported years.[7,8] Fall-related mortality was defined as the number of deaths attributed to falls per 100 000 people, and fall-related deaths refer specifically to fatalities resulting from such incidents. Fall-related deaths were categorised according to the ICD code (appendix pp 19–20). To analyse mortality trends in detail, fall-related deaths were further stratified into subgroups based on specific ICD-10 mechanisms (appendix p 6).[9,10] All ICD codes consistently represent fatalities due to falls, ensuring an accurate capture of fall-related mortality across different periods.[11] Population data for each country were obtained from the UN dataset to calculate mortality rates.[12] We further stratified countries by income level (based on World Bank country classification),

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Human Development Index (HDI; appendix p 7), and geographical region to identify distinct patterns in fall-related mortality rates (appendix pp 21–22).

Statistical analysis

We calculated age-standardised fall-related mortality rates to adjust for differences in the population distribution across countries over time (appendix p 6). For trend analysis, we used a locally weighted scatter plot smoother (LOESS) curve to generate a smoothed curve of trends in fall-related mortality over time for the countries included in this study (appendix pp 7–10).[7] The LOESS curve is a smoothing technique that connects data points while accounting for variations, thus enabling the detection of comprehensive trends and patterns within the data.[13] The smoothing parameter was determined through the default optimisation procedure in the SAS software (appendix pp 10–12). The data are expressed as mortality rates with 95% CIs. A two-sided p value of less than 0·05 was considered significant. The LOESS curve was estimated through the default optimisation procedure in SAS (version 9.4; SAS, Cary, NC, USA), and Python (version 3.11.4; Python Software Foundation, Wilmington, DE, USA) was used for visualisation.

HDI, Socio-demographic Index, reverse Gini coefficient, Environment Performance Index (EPI), latitude, and obesity rate were used to analyse the association between fall-related mortality and various socioeconomic indicators (appendix p 12). Based on the latest indices reported by each institution, scatter plots displaying the mean fall-related mortality rates for each country were produced, and linear regression was applied to assess the associations. Data are expressed as β coefficients and p values.

We used an extended version of the classic age–period–cohort models, known as Bayesian age–period–cohort (BAPC) models, to estimate fall-related mortality rates from 2022 to 2040 in HICs and UMICs (appendix pp 12–13).[14] These models posit that the logit risk of mortality for a specific age group and period is determined by a linear function, incorporating age, period, and cohort factors to thoroughly examine changes in mortality rates over time.[14] Moreover, the models accommodate different age, period, and cohort effects through various combinations, including constant or linear time trends (random walk of the first or second order; appendix pp 13–14).[15] To determine the optimal parameters for each effect, we assessed the model prediction accuracy from 2011 to 2021 using data from 1990 to 2010, with root mean square errors as the evaluation metric. Furthermore, the BAPC model was applied to different categories, including sex (men and women) and age groups (55–64, 65–74, 75–84, and ≥85 years), to account for heterogeneity.

The model represented prediction results as age-standardised estimates with 95% credible intervals (CrIs; appendix pp 14–15). The statistical modelling was conducted using the bamp package in the R software (version 4.1.2).[14]

We conducted a decomposition analysis to investigate the impact of population growth, population ageing, and epidemiological change on trends in fall-related mortality rates from 1990 to 2021 and projected them from 1990 to 2040.[16] Gupta's method addresses limitations found in other decomposition approaches, which might exhibit sensitivity to decomposition order and reference group selection, thereby reducing the risk of inconsistent results from identical datasets.[16] The contributions of the assessed factors are represented as increases or decreases in overall mortality, as indicated by positive and negative values (appendix pp 15–16).

Role of the funding source

The funder of the study had no role in the study design, data collection, data analysis, data interpretation, or writing of the report.

Results

59 HICs and UMICs that reported data from at least 26 of the 32 years within the observation period (1990–2021) were included in the analysis (appendix pp 17–18). According to the WHO Mortality Database, age-standardised fall-related mortality rates (per 100 000 people) from 59 countries decreased substantially from 23·21 (95% CI 21·30–25·12) in 1990 to 11·01 (9·94–12·08) in 2009, followed by a slight increase to 12·50 (10·36–14·64) in 2021. In 1990, age-standardised fall-related mortality rates were higher in HICs than in UMICs (27·76 [95% CI 25·49–30·03] *vs* 11·54 [9·33–13·76]). From 1990 to 2021, age-standardised fall-related mortality (per 100 000 people) in HICs decreased substantially to 13·06 (11·88–14·24; –52·94%) by 2012, followed by a slight increase to 13·77 (11·20–16·34; 5.44%) by 2021, and UMICs decreased to 6·48 (5·28–7·68; –43·83%) by 2005, and then increased to 9·70 (9·33–13·76; 49·69%) by 2021 (figure 1; appendix pp 26–28, 81–82).

The patterns in fall-related mortality rates by economic status reveal a pronounced decline in HICs and a comparable decreasing trend in UMICs; however, a slight increase in mortality rates in both groups was noted up to 2021. The LOESS curve indicated that the mortality rate (deaths per 100 000 people) was high in Europe and the Americas compared with other regions in 1990 (Europe, 32·06 [95% CI 29·16–34·95]; the Americas, 17·34 [14·08–20·60]), rapidly decreasing (Europe, 13·20 [11·60–14·80] in 2012, –59·01%; the Americas 7·79 [6·03–9·54] in 2003, –55·12%), and increasing (Europe, 14·68 [11·39–17·98] in 2021, 11·72%; the Americas, 11·99 [8·39–15·59] in 2021, 53·91%; appendix pp 26–28, 83–84).

Regarding HDI, the countries with very high HDI values showed a substantial decline in age-standardised fall-related mortality rates per 100 000 people from 1990 to 2011, decreasing by 53·43% (25·10 [95% CI 23·00–27·20] in 1990 to 11·68 [10·53–12·83] in 2011). However, mortality rates increased by 10·10% from 2011 to 2021, reaching 12·86 (10·49–15·23). This gap decreased in 2021 to an

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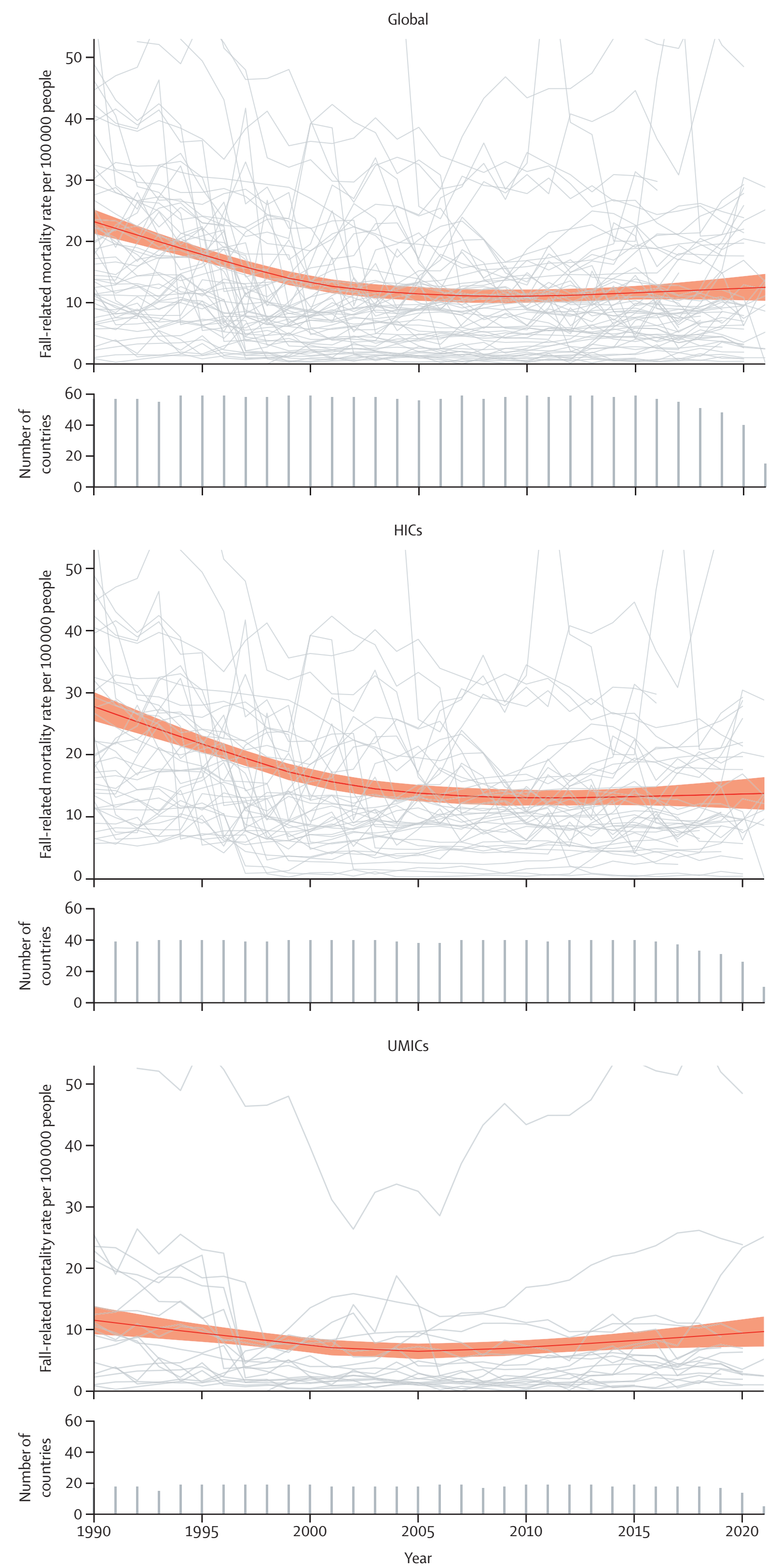

Figure 1: **Age-standardised fall-related mortality rates (per 100 000 people) of the global, HIC, and UMIC populations across 59 countries from 1990 to 2021**

The grey lines show age-standardised fall-related mortality rates for each country, the red lines are LOESS-smoothed curves, and the red shaded areas represent the 95% CIs of the LOESS estimates. The x-axis labels, representing years (1990, 1995, 2000, 2005, 2010, 2015, and 2020), are consistent across both the top and bottom plots. The y-axis is capped at 50 to provide a clearer view of the LOESS range and trends, because it focuses on most data points. Although there are some outliers, this approach ensures that the main patterns and relationships are not obscured by extreme values. HICs=High-income countries. LOESS=locally weighted scatterplot smoother. UMICs=upper-middle-income countries.

age-standardised fall-related mortality rate per 100 000 people of 12·86 (10·49–15·23) in very high HDI countries and 11·02 (7·66–14·38) in high HDI countries (appendix pp 26–28).

The fall-related mortality rates for both men and women decreased from 1990 to 2010 and then increased again from 2010 to 2021. Throughout these periods, the mortality rates in men were consistently higher than those in women. Fall-related mortality rates also exhibited sex disparities based on income and HDI. Notably, the increase in fall-related mortality rates from 2010 to 2021 in women was substantially more than that in men in regions including Asia (56·92% for men and 78·27% for women), the Americas (42·71% for men and 60·34% for women), and Europe (2·18% for men and 19·91% for women; appendix pp 29–34, 85–89). Fall-related mortality rates are higher in men than in women, with both sexes showing a decline until 2010, followed by an increase. Across all fall mechanisms, including slips, trips, falls from heights, and unspecified falls, mortality rates showed an overall declining trend across sexes, with notable differences in their contributions to global fall-related mortality (appendix pp 26–34).

A pronounced increase in age-standardised fall-related mortality rates was observed among older populations, particularly those aged 85 years and older, with the rate per 100 000 people increasing sharply from 5·00 (95% CI –4·94 to 14·94) in 1992 to 76·74 (62·10 to 91·39) in 2021 (appendix pp 35–73, 78–79). An increasing trend associated with age was observed irrespective of sex and occurred in both HICs and UMICs, across all the HDI groups, and all the continents (figure 2; appendix pp 35–73, 90–93). The most substantial sex gap in age-specific fall-related mortality occurred in people aged 85 years and older, with men having a substantially higher mortality rate from falls than women in countries with a very high HDI (4·34–84·72 deaths per 100 000 people for men *vs* 6·42–68·29 deaths per 100 000 people for women in 1992 and 2021; figure 2; appendix pp 35–73, 90–93).

The age-standardised fall-related mortality rates, reflecting the country-specific means, are positively associated with reverse Gini coefficients (β=22·58 [95% CI 0·45 to 44·72], p=0·046), the Socio-demographic Index (β=42·29 [10·26 to 74·32], p=0·011), EPI (β=0·19 [0·05 to 0·33], p=0·0090), and latitude (β=0·11 [0·01 to 0·21], p=0·032). However, age-standardised fall-related mortality rates were not significantly associated with HDI (β=37·56 [–0·94 to 76·06], p=0·056) and obesity (β=–0·03 [–0·32 to 0·26], p=0·85; figure 3; appendix p 94).

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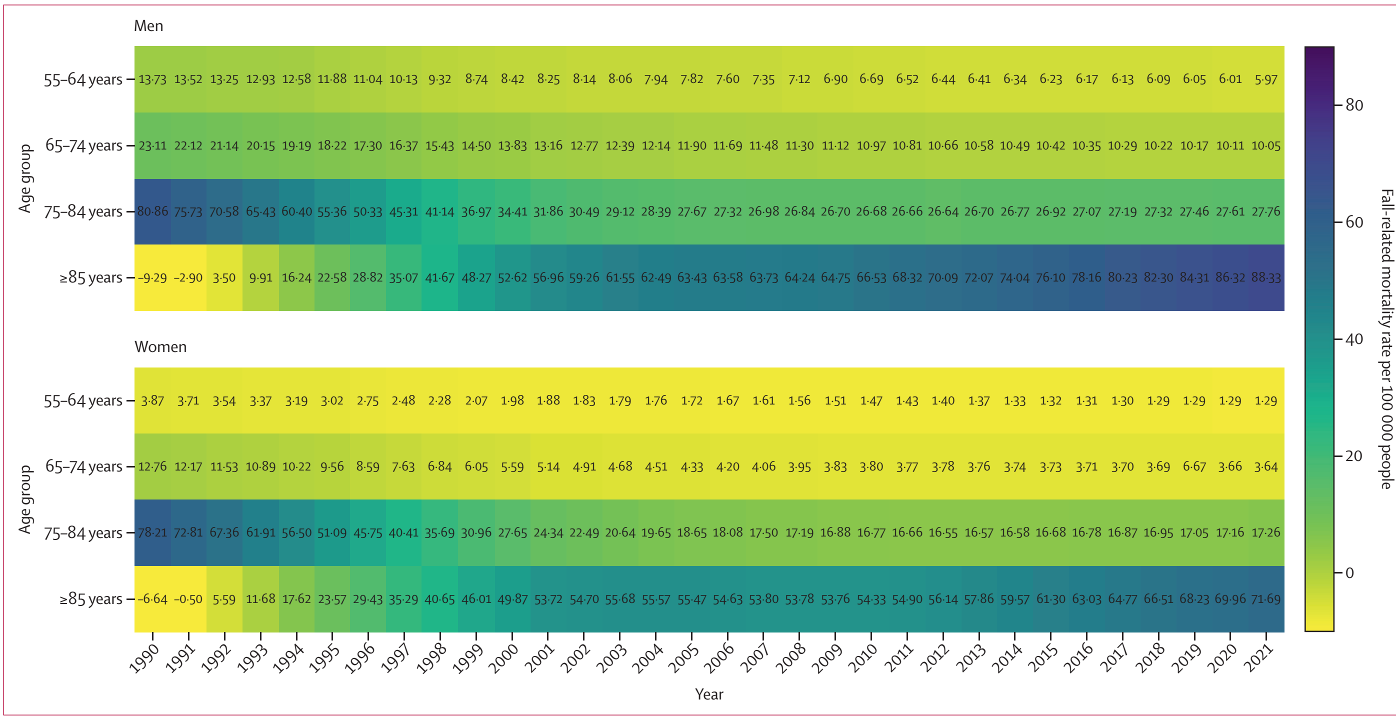

Figure 2: **LOESS smoothed fall-related mortality rates (per 100 000 people) by sex and age across 59 countries, 1990–2021**
LOESS=locally weighted scatterplot smoother.

The BAPC models predicted that age-standardised fall-related mortality rates will increase gradually, with 14·80 deaths per 100 000 people (95% CrI 14·04–15·59) in 2021, 16·50 (13·16–23·61) in 2030, and 19·48 (7·02–98·84) in 2040 (figure 4; appendix p 74). Additionally, the BAPC model assessed the variations in age, period, and cohort effects using data from 1990 to 2010 to forecast values for 2011 to 2021. The model with the lowest root mean square error was selected as optimal (appendix pp 75–76), and the hyperparameter values associated with each factor were subsequently determined (appendix p 77).

The decomposition analysis indicated that the increase in fall-related deaths from 1990 to 2021 was primarily driven by population growth, which contributed to 21 464 deaths globally. Epidemiological changes and ageing had relatively minor roles during this period; their impact exhibited variation across regions and sexes (figure 5; appendix pp 78–80). Projections for 2040 suggest that population growth will remain the largest contributor, with an estimated 145 037 additional deaths globally. This projection reflects how the absolute number of deaths can increase despite a declining rate, because the growing population amplifies the total burden of fall-related mortality.

Discussion

This study used the WHO Mortality Database to report age-standardised fall-related mortality rates and their trends from 1990 to 2021 across 59 countries from four continents (Asia, the Americas, Europe, and Oceania). The landscape of fall-related mortality has had notable shifts from 1990 to 2021, with the age-standardised mortality rate initially decreasing substantially by 52·6% from 23·21 per 100 000 people in 1990 to 11·01 per 100 000 people in 2009, before increasing to 12·50 per 100 000 people in 2021. The initial decline in fall-related mortality rates (1990–2009) likely reflects advancements in health care and fall prevention, while the subsequent increase (2009–21) can be attributed to population ageing and the growing prevalence of chronic conditions among older adults.[1,17] Regional disparities are evident, with Europe and the Americas displaying the highest rates in 1990, substantial declines in 2012, and subsequent increases in 2021. Economic factors played a crucial role; HICs initially exhibited higher mortality rates but experienced a decline until 2012, followed by a slight increase. By contrast, UMICs showed a decrease until 2005 and a marked increase by 2021. Sex and age differences were substantial, with men consistently having higher mortality rates and increased age-standardised mortality rates (ASMRs) than women of the same age group, particularly among individuals aged 85 years and older in UMICs. These differences may be explained by the higher risk of severe falls and associated complications among men in this age group, as well as behavioural and physiological factors such as participation in riskier activities and greater fall severity in men.[18] Projections indicate a concerning rise in fall-related deaths per 100 000 people, from 14·80 in 2021 to 19·48 by 2040, emphasising the need for targeted, region-specific, and economically sensitive interventions. The increased fall-related deaths from 1990 to 2021 and

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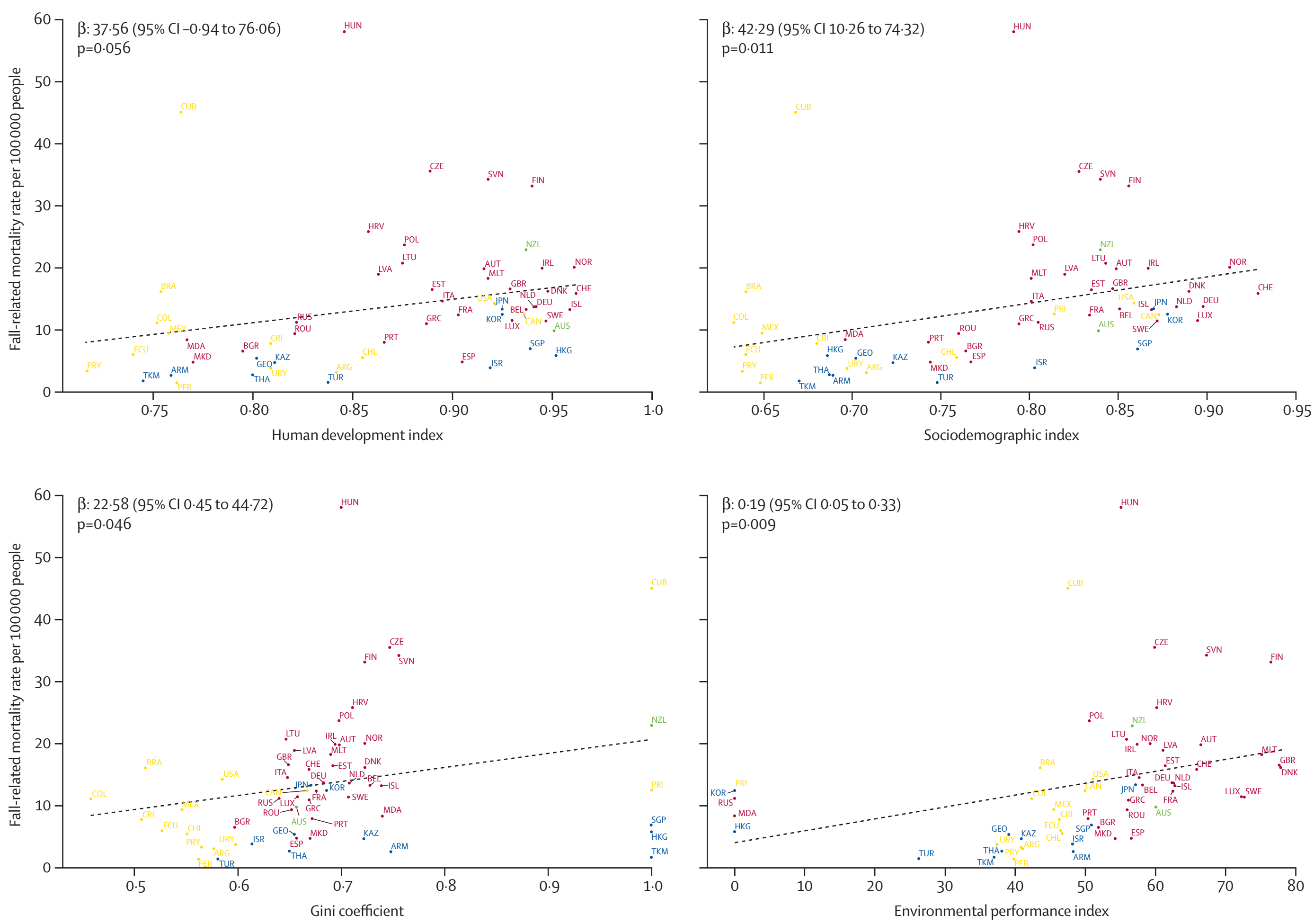

***Figure 3:* Association between age-standardised fall-mortality mortality rate (per 100 000 people) and the Human Development Index, Socio-demographic Index, Gini coefficient, and Environmental Performance Index.**

ARG=Argentina. ARM=Armenia. AUS=Australia. AUT=Austria. BEL=Belgium. BGR=Bulgaria. BRA=Brazil. CAN=Canada. CHE=Switzerland. CHL=Chile. COL=Colombia. CRI=Costa Rica. CUB=Cuba. CZE=Czech Republic. DEU=Germany. DNK=Denmark. ECU=Ecuador. ESP=Spain. EST=Estonia. FIN=Finland. FRA=France. GBR=United Kingdom. GEO=Georgia. GRC=Greece. HKG=Hong Kong Special Administrative Region. HRV=Croatia. HUN=Hungary. IRL=Ireland. ISL=Iceland. ISR=Israel. ITA=Italy. JPN=Japan. KAZ=Kazakhstan. KOR=South Korea. LTU=Lithuania. LUX=Luxembourg. LVA=Latvia. MDA=Moldova. MEX=Mexico. MKD=North Macedonia. MLT=Malta. NLD=Netherlands. NOR=Norway. NZL=New Zealand. PER=Peru. POL=Poland. PRI=Puerto Rico. PRT=Portugal. PRY=Paraguay. ROU=Romania. RUS=Russia. SGP=Singapore. SVN=Slovenia. SWE=Sweden. THA=Thailand. TKM=Turkmenistan. TUR=Türkiye. URY=Uruguay. USA=United States of America.

from 1990 to 2040 can be attributed to the growth in population. Although these are rates, the rise can be attributed to an overall increase in the at-risk population driven by demographic shifts, particularly the growth in older age groups. Association analyses further underscored the impacts of sociodemographic indicators, environmental quality, and socioeconomic development on fall-related mortality, highlighting the importance of comprehensive strategies for addressing these factors. These disparities underscore substantial differences in health-care systems, data collection practices, and social support between HICs and UMICs, which might influence the observed trends in fall-related mortality. HICs benefit from advanced health-care infrastructures and reliable data reporting, while UMICs face challenges such as inconsistent access to health care and variable data quality, which can undermine the reliability of the data.

Previous studies on fall-related mortality among older people have predominantly used regional data from sources such as the GBD or nation-specific databases. In contrast, this study is the first to employ the WHO Mortality Database for a comprehensive analysis of global trends spanning the past 30 years. Previous studies have largely relied on the GBD or nation-specific databases (eg, The US Centers for Disease Control and Prevention's Wide-ranging Online Data for Epidemiologic Research). In a previous study using GBD 2017 in western Europe from 1990 to 2017, the death rates due to falls in older people (aged >70 years) were highest in the Netherlands and Switzerland, and the lowest were in Portugal and Greece.[4] In our study, mortality rates

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(per 100 000 people) were lowest in France (2·35) and Bulgaria (4·39) and highest in Denmark (21·25) and the Netherlands (21·14). Another study using the GBD data showed that globally, total fall deaths have increased steadily since 1990, doubling by 2017; the age-standardised mortality rate was 9·2 per 100 000 people. However, ASMRs (5·9%) have declined slightly over the same period.[19] In our study, the ASMR was 11·91 per 100 000 people in 2017, a decrease of 48·69% from 1990 to 2017. This decrease in mortality rate is consistent with previous studies' findings.

The mortality rate due to falls among older adults increased by 31% (3·0% annually) from 2007 to 2016 in the USA, and fall-related mortality was 61·6 per 100 000 residents aged 65 years and older in 2016. This report showed race, sex, and age differences; the fastest increasing rate was among those aged 89 years and older (3·9% annually).[20] In another study conducted between 1999 and 2020, fall-related deaths among adults aged 65 years and older increased in number and rates for the overall population and every population subgroup.[5] However, the magnitude of the increase varied and was heterogeneous in how mortality has changed over time.[5] These results are consistent with a 2010 study that estimated a 42% increase from 2000 to 2006[21] and our findings.

Fall-related mortality rates have generally declined since 1990 but have trended upward since 2009, primarily due to the increasing older adult population.[22] Ageing leads to declines in muscle strength and balance and a higher prevalence of chronic conditions such as osteoporosis and arthritis, heightening the risk of falls.[18] HICs benefit from advanced health-care infrastructure and reliable mortality reporting, whereas UMICs often face resource limitations, leading to inconsistent data and disparities in fall prevention efforts.[23] Additionally, polypharmacy among older adults exacerbates fall risks through side-effects such as dizziness and cognitive impairment, and disparities in built environments—ranging from urban hazards to uneven rural terrains—further contribute to variations in fall-related mortality trends.[18]

In the past decade, research on the causes and prevention of falls has led to implementing more effective evidence-based strategies. Data collection on fall incidents provides insights that drive policies and practices for fall prevention. A study has reported that the nearly seven-fold increase in death rates from other falls on the same level (ie, falls that occur without elevation change) among individuals aged 65 years and older is likely attributable to improved reporting quality, despite minor and insignificant increases in emergency department visits and hospitalisation rates for falls.[24] Additionally, mortality statistics have demonstrated increased fall-related mortality rates among older adults.

The interplay between sociodemographic and environmental indices, including the Socio-demographic Index, EPI, HDI, Gini Index, and fall-related mortality rates, reveals key insights. Regions with higher income inequality struggle with fall prevention and care. Effective interventions should consider these socioeconomic and environmental contexts and focus on maintaining health-care quality, addressing the needs of ageing populations in areas with high EPI and HDI, reducing income inequality, and improving health-care access in regions with high Gini indices. These factors elucidate the age and sex differences in fall-related mortality identified in this study.

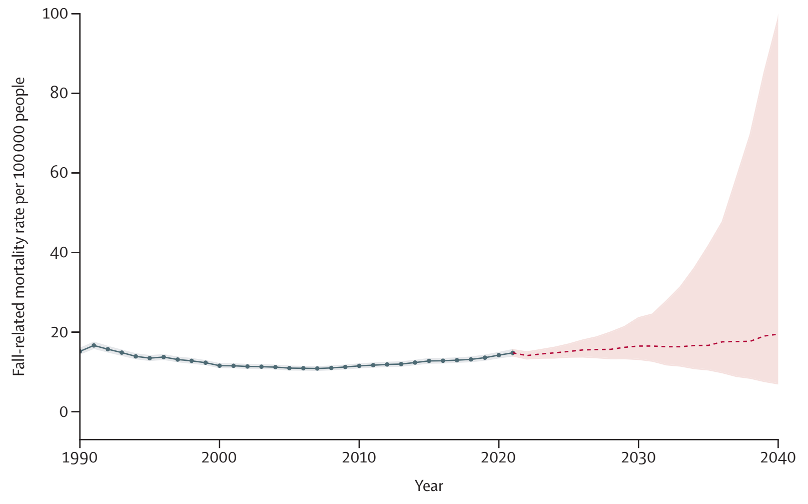

***Figure 4:* Projections in age-standardised fall-related mortality rate (per 100 000 people) from 1990 to 2040 by Bayesian age–period–cohort models**

The black points represent observed data (1990–2021), the red points indicate projections (2022–40), and the shaded areas show the 95% credible intervals.

Longitudinal analyses have revealed that although the mean age of patients sustaining hip fractures—a substantial category of fall-related trauma accounting for 50% of fatalities—has progressively increased, the associated 1-year mortality rate has decreased from 27% to 20%.[25] This improvement reflects advancements in prevention, medical care, and timely surgical treatment. Higher national economic levels are linked to better health-care quality and improved outcomes, including lower mortality and disability rates from injuries. Analysing fall-related mortality trends in different subgroups can help create more effective and targeted prevention strategies.

Effectively reducing fall-related mortality among older adults necessitates a multifaceted approach integrating comprehensive fall prevention strategies with systemic health-care reforms. Central to this effort is the implementation of Comprehensive Geriatric Assessments (CGAs), which enable the development of personalised care plans addressing critical risk factors such as frailty, sarcopenia, and polypharmacy.[26,27] These individualised plans should be regularly monitored and adjusted to meet the evolving needs of older adults. Involving occupational therapists can mitigate the negative effects of the home environment on falls, while WHO's Intrinsic Capacity assessment framework offers an effective alternative when CGAs are impractical for community-dwelling, frail individuals.[28] The Intrinsic Capacity framework emphasises optimising functional abilities rather than focusing solely on disease, demonstrating strong predictive value for

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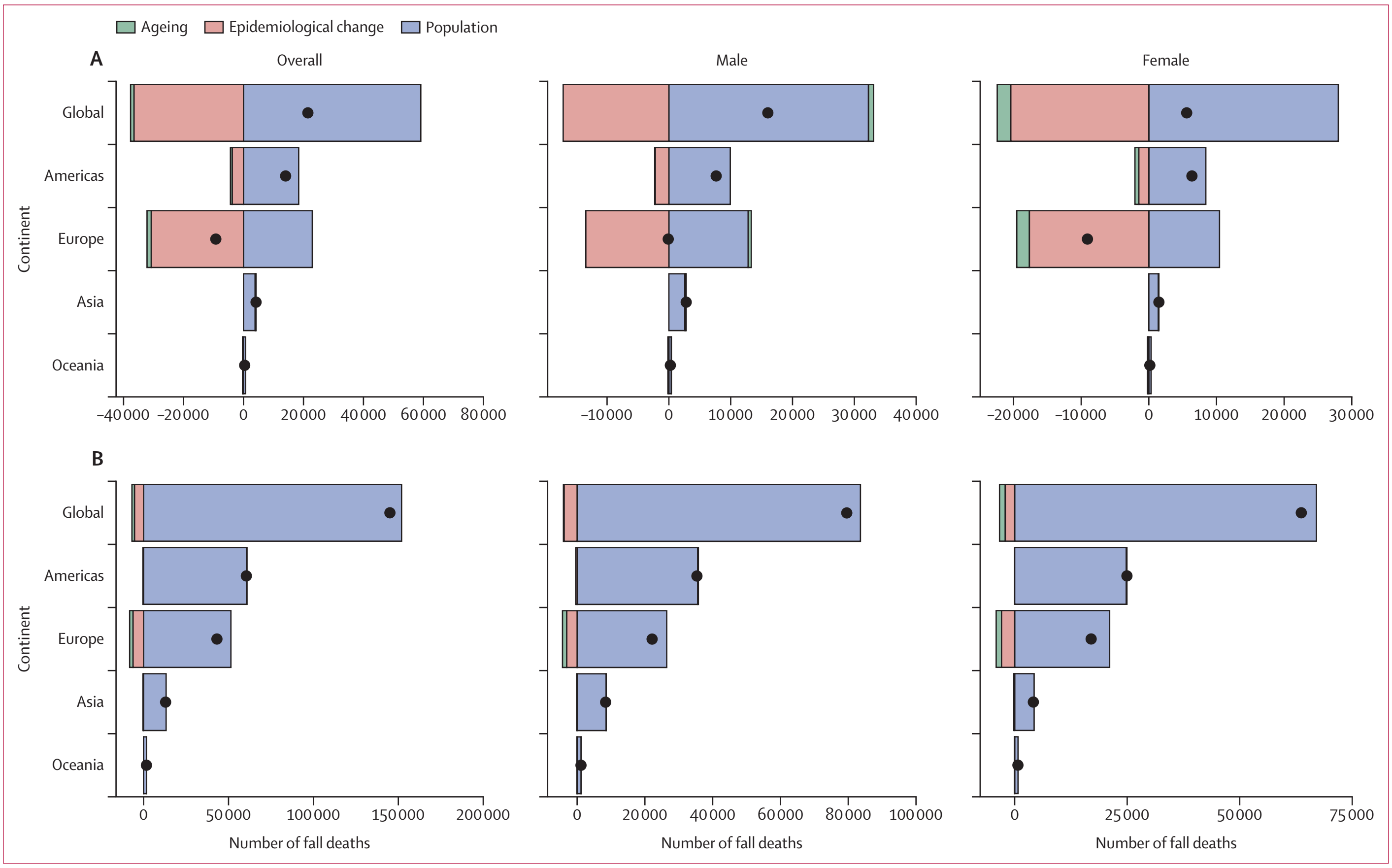

Figure 5: **Changes in the number of fall-related deaths (per 100 000 people) associated with ageing, epidemiological change, and population from 1990 to 2021 (A) and 1990 to 2040 (B) by sex**
Note that the scales on the x-axes are different for each plot. The dots represent the integrated outcomes of the three factors: ageing, epidemiological change, and population.

fall risk.[29] Additionally, environmental modifications, including home safety enhancements and age-friendly urban planning, are essential, along with promoting multicomponent exercise programmes focusing on strength and balance in community settings.[30]

Policy development and enhancements in health-care infrastructure are crucial to support these multifactorial interventions. Prioritising evidence-based secondary fall prevention measures, such as fracture liaison services and osteoporosis treatment, is essential.[30] Establishing national standards for systematically collecting and analysing fall-related data will facilitate monitoring trends and dynamically adjusting public health strategies. Policy makers should focus on preventive measures tailored to ageing populations, including targeted interventions for groups at high risk and adaptable strategies that address the rising fall-related mortality associated with demographic shifts.[31] Finally, a multidimensional and integrated approach is essential to effectively addressing fall prevention and fall-related mortality among older adults.[32] This proactive strategy reduces immediate fall risks and strengthens the public health infrastructure, ultimately enhancing the quality of life of older individuals.

This study had several limitations. First, changes in cause-of-death coding might have occurred during the study period from 1990 to 2021, contributing to a decrease or increase in fall-related mortality. Second, difficulty identifying fall-related deaths can lead to substantial differences in the reporting outcomes. However, their classification can be ambiguous when acute incidents do not cause fall-related deaths. This classification might vary substantially depending on each country's health-care system and sociocultural awareness. These factors might contribute to several variables, potentially leading to under-reporting or misclassification of fall-related deaths.[10] Hence, we used the WHO Mortality Database, which uses ICD codes, a globally recognised and standardised disease classification system. Third, data quality bias in some countries might arise owing to incomplete mandatory registration systems and insufficient health services. Additionally, reporting bias can occur in countries that do not submit cause-of-death data to WHO. Thus, our study included only countries that consistently reported cause-of-death data to WHO for at least 80% of the observation period. LICs and MICs were excluded from the analysis due to limited availability and inconsistency in fall-specific mortality data. In many LICs and MICs,

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cause-of-death data are challenging to obtain, primarily because of non-functional or non-existent systems for recording such information, as well as a lack of medical certifiers to complete death certificates, as noted in the WHO Mortality Database.[6] This inconsistency limits the feasibility of reliable cross-country comparisons. Therefore, the analysis focuses on HICs and UMICs where fall-related data are more robust, allowing for a clearer examination of trends and contributing factors.[33] Nevertheless, fall-related mortality remains a substantial issue in LICs and MICs, and further research is needed to address this concern.[3] Fourth, although our study endeavoured to correlate fall-related mortality with various socioeconomic factors, such as age and sex, other potential confounding variables were not accounted for. These factors include cultural influences, health-care accessibility, physical activity levels, and environmental conditions, which might substantially affect fall-related mortality.

In conclusion, this study used the WHO Mortality Database to investigate trends in age-standardised fall-related mortality rates from 1990 to 2021 across 59 countries. The findings show a complex, multifaceted pattern, with an initial 52·54% decrease in the rate from 1990 to 2009, followed by a 13·53% increase until 2021, accompanied by substantial disparities across age, sex, economic status, and geographical regions. Predictive models projected a gradual increase in ASMR over the next 20 years, emphasising the need for urgent and proactive implementation of targeted intervention and prevention programmes tailored to ageing demographic and socioeconomic contexts and enhanced fall prevention strategies.

Contributors

DKY and L-KC had full access to all data in the study and took responsibility for the integrity of the data and the accuracy of the data analysis. DKY, L-KC, and SuK accessed and verified the underlying data reported in this study. All authors have approved the final version of the manuscript before submission. Study concept and design: SuK, SoK, and DKY. Data acquisition, analysis, and interpretation: SoK and DKY. Drafting of the manuscript SuK, SoK, L-KC, and DKY. Critical revision of the manuscript for important intellectual content: all authors. Statistical analysis: SoK and DKY. Study supervision L-KC and DKY. SuK and SoK contributed equally as first authors. DKY supervised the study and served as the guarantor. DKY is the senior author.

Declaration of interests

We declare no competing interests.

Data sharing

The WHO Mortality Database is a global collaborative dataset of mortality rates reported by WHO member countries. The study protocol and statistical codes are available from Dong Keon Yon (yonkkang@gmail.com). WHO makes this dataset available through a data-use agreement.

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