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Global burden of road injuries and their attributable risk factors from 1990 to 2021: A systematic analysis for the global burden of disease study 2021

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ABSTRACT

Objective: To systematically estimate the burden of road injuries and associated risk factors.

Methods: Data on incidence, deaths, and disability-adjusted life years (DALYs) with 95 % uncertainty intervals, by age, sex, sociodemographic index, region, and country, from 1990 to 2021, were obtained from the Global Burden of Disease Study 2021. In addition, we obtained the numbers of DALYs and deaths attributed to risk factors. Joinpoint regression analysis was used to calculate the average annual percentage changes and 95 % confidence intervals (CIs).

Results: In 2021, the incident cases of road injuries were 50.3 million (95 % uncertainty interval: 45.7 to 55.2) globally, with an age-standardized incidence (ASIR) of 627.8 per 100,000 population (95 % uncertainty interval: 570.6 to 688.1). From 1990 to 2021, the ASIR was decreased by an average of 1.52 (95 % CI: −1.55 to −1.49) per year. Substantial heterogeneity was observed, particularly among youth aged 25–29 years, males, and high-income North America. Road injuries caused 65.1 million (95 % uncertainty interval: 60.7 to 69.9) DALYs and 1195.7 thousand (95 % uncertainty interval: 1118.2 to 1275.7) deaths in 2021. High burden was observed in older people, males, Central Sub-Saharan Africa, and countries with low income. Motor vehicles (36.6 %) and pedestrians (36.8 %) were the main causes of death. In particular, 72.2 % of road injuries were attributable to occupational injuries for males, while 57.7 % were attributable to low bone mineral density for females.

Conclusion: This study suggests a decreasing global burden of road injuries. Nonetheless, road safety remains a significant global public health issue.

1. Introduction

Road injuries are a major cause of death and a serious public health challenge worldwide. In 2021, there were an estimated 1.19 million road traffic deaths globally, which corresponds to a mortality rate of 15 per 100,000 population (*Global status report on road safety* 2023. Health and Safety, 2023; Collaborators GBDCoD, 2024). Road injuries affect not only drivers but also pedestrians, cyclists, and motorcyclists. According to the Global Status Report on Road Safety 2023, road injuries remained the leading cause of death for children and young people aged 5–29 years and was the 12th leading cause of death when all ages are considered in 2019 (*Global status report on road safety* 2023. Health and Safety, 2023). A significant burden was found in low-income and middle-income countries, where 92 % of deaths occur in these regions (*Global status report on road safety* 2023. Health and Safety, 2023). Apart from the deaths and non-fatal injuries, the economic burden posed by road injuries is also considerable and available. In 2014, the economic cost of serious and fatal road injuries worldwide was estimated to be $1.8 trillion, which equated to an average of 3 % of gross domestic product (GDP) in middle-income countries and 5 % of GDP in low-income countries (Bank TW, 2014).

Reducing the burden of road injuries is a key target of the third Sustainable Development Goals (SDGs) (collaborators NCDC, 2018). It is crucial to understand the current status and temporal trends of the

Abbreviations: AAPC, average annual percent change; ASIR, age-standardized incidence rate; ASDR, age-standardized death rate; CI, confidence interval; DALYs, disability-adjusted life years; GBD, global burden of disease; GDP, gross domestic product; SDG, sustainable development goals; SDI, sociodemographic index.

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burden of road injuries at both global and local levels to inform evidence-based policy. Since the early 1990s, the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) has systematically and comprehensively estimated global health and health loss across stratified age groups, locations, and sexes for the years (Murray, 2022). Previous studies based on the GBD database have significantly advanced our understanding of the burden of road injuries (James et al., 2020; *Lancet Public Health*, 2020; Davila-Cervantes, 2021; Zhao et al., 2022; Xu et al., 2022; Ou et al., 2023; Seif et al., 2024; He et al., 2023; Borges et al., 2021), or transport injuries (Wan et al., 2023). However, these studies relied on GBD 2017 or GBD 2019, which included data only up to 2017 and 2019, respectively.

Recently, GBD 2021 provided current information on the distribution and burden of diseases and injuries across time, age, sex, location, and sociodemographic groups for the years 1990–2021 (Diseases and Injuries, 2024). Hence, in the present study, we conducted a comprehensive and up-to-date analysis to investigate the incidence, disability-adjusted life-years (DALYs), and death related to overall and four common road injuries from 1990 to 2021 based on the GBD 2021 database. In addition, we estimated the risk-attributable burden of road injuries at global levels using DALYs and deaths. This study aims to provide a timely reflection of the latest trends in road injuries. Furthermore, it thoroughly examines the differences in risk factors across various sexes and regions, offering a more accurate foundation for developing targeted policies.

2. Methods

2.1. Ethics statement

The data utilized in this study were sourced from the publicly accessible GBD 2021 database, which exclusively contains non-identifiable information. Consequently, this study was granted exemption from ethical approval requirements by institutional review boards.

2.2. Data source

The GBD 2021 examined 371 diseases and injuries in 204 countries and territories, including subnational estimates for 21 regions, providing detailed data on incidence, prevalence, mortality, DALYs, and age-standardized rates (Diseases and Injuries, 2024). The data on overall road injuries and four common types of road injuries (pedestrian road injuries, cyclist road injuries, motorcyclist road injuries, and motor vehicle road injuries) were obtained from GBD 2021 using the online Global Health Data Exchange (GHDx) query tool (https://vizhub.healthdata.org/gbd-results/). The data encompassed both fatalities and non-fatal road injuries. The counts and rates of incidence, DALYs, and deaths were directly extracted at the global level, 21 regions, and 204 countries and territories. Incidence is defined as the occurrence of road injuries, while mortality refers to deaths resulting from road injuries. DALYs represent the sum of years of potential life lost due to premature mortality and the years lived with disability associated with road injuries. The 95 % uncertainty intervals were generated using the 25th and 75th ordered values out of 1000 draws from the posterior distribution. The definition and classification of road injuries in GBD study was based on the International Classification of Diseases-10 (ICD-10) (James et al., 2020) (Davila-Cervantes, 2021).

Data on sex, socio-demographic index (SDI) categories, and various age groups were collected. Specifically, the SDI for 204 countries and territories is classified into five regions based on quintiles: low, low-middle, middle, high-middle, and high. This composite indicator is derived from lag-distributed income per capita, total fertility rates among individuals younger than 25 years, and the average educational attainment of individuals aged over 15 years (Collaborators GBDCoD, 2024). It is closely linked to health outcomes and serves as a composite indicator for evaluating developmental conditions. Age was classified into 20 subgroups: 0–4, 5–9, 10–14, 15–19, 20–24, 25–29, 30–34, 35–39, 40–44, 45–49, 50–54, 55–59, 60–64, 65–69, 70–74, 75–79, 80–84, 85–89, 90–94, and 95^{+} years. We conducted the analysis separately for each stratum, which included sex and various age groups. The data were extracted directly using the online GHDx query tool.

In addition, risk factors associated with road injuries were obtained. For the risk factors in GBD 2021, exposure data were modeled using spatiotemporal Gaussian process regression or DisMod–MR 2.1. Detailed information on the definitions of these risk factors and their relative risks for road injuries can be found in previous studies (Collaborators, 2024).

2.3. Statistical analysis

Temporal trends from 1990 to 2021 were evaluated using Joinpoint regression analysis by calculating the average annual percentage changes (AAPCs) and their 95 % confidence intervals (CIs) for the incidence, DALYs, and mortality using the logarithmic linear model ($\ln y = xb$). The detailed information for calculating the AAPC and the 95 % CI is presented in the **Supplementary Methods**. All statistical analyses and visualizations were conducted using Joinpoint software (version 5.0.2) provided by the United States National Cancer Institute (Kim et al., 2022), and R software (version 4.3.3). A two-tailed *P*-value less than 0.05 was considered statistically significant.

3. Results

3.1. Global burden and temporal trends of road injuries

In 2021, there were 50.3 million incident cases of road injuries globally (95 % uncertainty interval: 45.7–55.2 million), with an age-standardized incidence rate (ASIR) of 627.8 per 100,000 population (95 % uncertainty interval: 570.6–688.1) (Table 1). From 1990 to 2021, the ASIR was decreased by an average of 1.52 (95 % CI: −1.55 to −1.49) per year. The ASIR for males (857.5 per 100,000 population) was higher than that for females (395.7 per 100,000 population). Among road injury types, motor vehicle road injuries had the highest ASIR (245.4 per 100,000 population), followed by pedestrian (140.6 per 100,000 population), cyclist (121.9 per 100,000 population), and motorcyclist (83.2 per 100,000 population) road injuries. In terms of SDI regions, we found high SDI regions with the highest ASIR (851.8 per 100,000 population), and the most significant decrease (AAPC: −2.10); while low SDI regions had the lowest ASIR (421.7 per 100,000 population), with the smallest decrease (AAPC: −0.59).

In 2021, the age-standardized death rate (ASDR) was 14.6 per 100,000 population (95 % uncertainty interval: 13.6–15.6), which significantly decreased compared to 1990 (AAPC: −1.30) (Table 2**)**. The ASDR for males was three times that for females. Pedestrian road injuries (10.2 per 100,000 population) were the leading cause of death in 1990, but both motor vehicle (5.4 per 100,000 population) and pedestrian (5.3 per 100,000 population) road injuries were the main causes of death in 2021. The mortality of motorcyclist road injuries showed an upward trend (AAPC: 0.19). Regions with a high SDI had the lowest ASDR (7.8 per 100,000 population), while regions with a low SDI had the highest (7.8 per 100,000 population).

In 2021, the age-standardized DALYs were 809.0 per 100,000 population (95 % uncertainty interval: 752.1–866.7), with an AAPC of 1.56 from 1990 to 2021 (**Table S1**). Males had the highest burden of DALYs, and road injuries related to motor vehicles had the highest DALYs. Regions with a high SDI had the lowest DALYs, and regions with a low SDI had the highest.

The age group of 20–24 years exhibited the highest incidence of road injuries, with a rate of 935.8 per 100,000 population. Motor vehicle and motorcyclist road injuries were the leading causes in this young population (Fig. 1**A.**). In contrast, the elderly population experienced the highest mortality rate, with pedestrian road injuries being the primary

Table 1
The incidence of road injuries and the temporal trends from 1990 to 2021.

Characteristics	1990		2021		1990–2021
	Cases (million) (95 % uncertainty interval)	ASIR (per 100,000) (95 % uncertainty interval)	Cases (million) (95 % uncertainty interval)	ASIR (per 100,000) (95 % uncertainty interval)	AAPC (95 % CI)
Global	54.8 (49.3 to 61.0)	1007.3 (908.5 to 1117.1)	50.3 (45.7 to 55.2)	627.8 (570.6 to 688.1)	−1.52 (−1.55 to −1.49)
Sex					
Male	35.4 (31.9 to 39.5)	1292.0 (1163.5 to 1431.7)	34.6 (31.4 to 38.0)	857.5 (776.6 to 940.6)	−1.91 (−1.93 to −1.89)
Female	19.4 (17.5 to 21.5)	719.0 (651.4 to 794.9)	15.7 (14.3 to 17.1)	395.7 (361.2 to 433.2)	−1.31 (−1.33 to −1.30)
Injury types					
Pedestrian road injuries	13.0 (11.3 to 15.2)	249.2 (216.6 to 286.1)	11.5 (10.0 to 13.3)	140.6 (122.3 to 162.6)	−1.83 (−1.87 to −1.78)
Cyclist road injuries	9.7 (7. 9 to 11.9)	177.8 (146.2 to 216.3)	9.8 (8.3 to 11.7)	121.9 (103.4 to 145.9)	−1.22 (−1.24 to −1.19)
Motorcyclist road injuries	5.3 (4.4 to 6.4)	97.1 (80.0 to 116.3)	6.7 (5.8 to 7.8)	83.2 (71.1 to 96.3)	−0.49 (−0.52 to −0.46)
Motor vehicle road injuries	23.3 (20.5 to 26.4)	422.4 (374.2 to 477.4)	19.5 (17.5 to 22.0)	245.4 (219.7 to 276.0)	−1.74 (−1.76 to −1.72)
SDI					
Low SDI	2.7 (2.5 to 2.9)	506.5 (466.5 to 551.1)	4.5 (4.2 to 4.8)	421.7 (393.2 to 452.2)	−0.59 (−0.62 to −0.56)
Low-middle SDI	7.7 (7.0 to 8.4)	640.8 (586.3 to 703.7)	10.1 (9.2 to 11.0)	524.7 (481.0 to 571.4)	−0.65 (−0.66 to −0.63)
Middle SDI	16.7 (14.7 to 18.8)	936.5 (831.6 to 1056.0)	16.3 (14.7 to 18.1)	645.1 (581.8 to 714.1)	−1.19 (−1.21 to −1.17)
High-middle SDI	13.4 (11.9 to 14.9)	1226.4 (1100.0 to 1368.1)	10.3 (9.3 to 11.4)	773.2 (697.2 to 855.1)	−1.48 (−1.51 to −1.45)
High SDI	14.4 (13.0 to 15.9)	1640.8 (1497.3 to 1810.0)	9.0 (8.2 to 9.8)	851.8 (771.2 to 934.0)	−2.10 (−2.13 to −2.06)
Regions					
High-income Asia Pacific	3.0 (2.7 to 3.2)	1691.5 (1553.7 to 1850.3)	1.0 (0.9 to 1.1)	544.8 (497.7 to 597.0)	−3.61 (−3.66 to −3.55)
Central Asia	0.6 (0.5 to 0.6)	770.0 (736.0 to 805.8)	0.6 (0.5 to 0.6)	562.7 (537.1 to 590. 7)	−1.01 (−1.08 to −0.94)
East Asia	11.9 (10.3 to 13.7)	949.0 (824.4 to 1088.0)	12.2 (10.8 to 13.9)	779.8 (686.5 to 876. 7)	−0.62 (−0.69 to −0.55)
South Asia	4.2 (3.6 to 4.8)	382.3 (335.0 to 438.8)	7.3 (6.4 to 8.2)	385.1 (339.8 to 434.6)	0.02 (0.00 to 0.03)
Southeast Asia	4.0 (3.7 to 4.4)	820.3 (754.7 to 893.1)	3. 5 (3.2 to 3.7)	478.9 (442.4 to 516.2)	−1.73 (−1.76 to −1.69)
Australasia	0.3 (0.3 to 0.4)	1649.7 (1547.8 to 1758.3)	0.19 (0.18 to 0.20)	653.2 (611.9 to 699.8)	−2.93 (−2.99 to −2.87)
Caribbean	0.3 (0.3 to 0.3)	743.7 (708.8 to 786.5)	0.27 (0.26 to 0.29)	575.5 (542.1 to 613.6)	−0.83 (−0.85 to −0.8)
Central Europe	1.6 (1.5 to 1.7)	1277.4 (1198.9 to 1370.6)	0.67 (0.63 to 0.72)	625.2 (582.8 to 672.0)	−2.29 (−2.34 to −2.25)
Eastern Europe	3.7 (3.2 to 4.3)	1677.0 (1462.3 to 1926.4)	1.9 (1.6 to 2.1)	973.6 (842.7 to 1108.9)	−1.73 (−1.86 to −1.6)
Western Europe	6.0 (5.6 to 6.4)	1582.6 (1494.0 to 1687.0)	2.3 (2.2 to 2.5)	588.2 (547.0 to 632.9)	−3.15 (−3.21 to −3.09)
Andean Latin America	0.28 (0.26 to 0.30)	727.7 (690.4 to 763.3)	0.38 (0.36 to 0.40)	558.6 (530.0 to 590.0)	−0.84 (−0.93 to −0.75)
Central Latin America	1.8 (1.6 to 2.0)	1059.8 (969.2 to 1158.1)	1.8 (1.7 to 2.0)	707.5 (651.53 to 766.0)	−1.29 (−1.35 to −1.23)
Southern Latin America	0.48 (0.46 to 0.51)	975.3 (927.6 to 1030.8)	0.62 (0.59 to 0.65)	901.3 (859.0 to 947.1)	−0.26 (−0.29 to −0.23)
Tropical Latin America	1.8 (1.6 to 2.1)	1182.2 (1022.9 to 1359.7)	2.0 (1.7 to 2.2)	833.5 (734.0 to 936.1)	−1.12 (−1.19 to −1.05)
North Africa and Middle East	6.6 (6.1 to 7.1)	1789.8 (1671.9 to 1914.0)	7.0 (6.6 to 7.4)	1105.8 (1042.4 to 1169.8)	−1.55 (−1.58 to −1.53)
High-income North America	5.6 (4. 8 to 6.5)	1986.8 (1716.4 to 2317.9)	4.2 (3.7 to 4. 7)	1162.6 (1019.8 to 1311.5)	−1.72 (−1.73 to −1.70)
Oceania	0.04 (0.04 to 0.05)	658. 7 (615.4 to 702.4)	0.08 (0.08 to 0.09)	589.3 (555.3 to 625.8)	−0.36 (−0.39 to −0.34)
Central Sub-Saharan Africa	0.55 (0.50 to 0.59)	896.5 (833.1 to 959.4)	1.00 (0.94 to 1.07)	745.2 (702.6 to 792.6)	−0.6 (−0.61 to −0.59)
Eastern Sub-Saharan Africa	0.82 (0.75 to 0.90)	429.9 (398.6 to 464.0)	1.15 (1.08 to 1.23)	305.4 (287.8 to 325.1)	−1.1 (−1.13 to −1.07)
Southern Sub-Saharan Africa	0.7 (0.6 to 0.8)	1354.7 (1164.6 to 1575.2)	0.7 (0.6 to 0.8)	878.0 (773.1 to 993.2)	−1.38 (−1.47 to −1.29)
Western Sub-Saharan Africa	0.76 (0.70 to 0.83)	371.0 (343.3 to 401.1)	1.5 (1.4 to 1.6)	326.2 (305.9 to 347.7)	−0.42 (−0.43 to −0.40)

Notes: The 95 % uncertainty intervals were generated using the 25th and 75th ordered values out of 1000 draws from the posterior distribution.
Joinpoint regression analysis was used for calculating the average annual percent change and 95 % confidence interval. *P*-value less than 0.05 was considered statistically significant. AAPC average annual percent change; ASIR age-standardized incidence rate; CI confidence interval; SDI sociodemographic index.

Table 2
The mortality of road injuries and the temporal trends from 1990 to 2021.

Characteristics	1990		2021		1990–2021
	Cases (thousand) (95 % uncertainty interval)	ASDR (per 100,000) (95 % uncertainty interval)	Cases (thousand) (95 % uncertainty interval)	ASDR (per 100,000) (95 % uncertainty interval)	AAPC (95 % CI)
Global	1107.3 (1054.9 to 1161.6)	21.8 (20.9 to 22.8)	1195.7 (1118.2 to 1275.7)	14.6 (13.6 to 15.6)	−1.30 (−1.42 to −1.19)
Sex					
Male	813.3 (770.6 to 855.4)	32.4 (30.8 to 33.9)	912.1 (850.9 to 979.5)	22.5 (21.0 to 24.1)	−1.19 (−1.30 to −1.08)
Female	294.0 (276.7 to 313.0)	11.6 (10.9 to 12.3)	283.6 (257.3 to 307.6)	6.8 (6.2 to 7.4)	−1.69 (−1.81 to −1.57)
Injury types					
Pedestrian road injuries	501.5 (446.0 to 547.1)	10.2 (9.1 to 11.1)	440.3 (392.4 to 488.0)	5.3 (4.8 to 5.9)	−2.06 (−2.25 to −1.87)
Cyclist road injuries	41.2 (35.0 to 47.3)	0.8 (0.7 to 1.0)	68.2 (59.7 to 78.1)	0.8 (0.7 to 0.9)	−0.14 (−0.24 to −0.04)
Motorcyclist road injuries	147.7 (124.4 to 170.3)	2.8 (2.3 to 3.2)	238.6 (213.3 to 261.4)	2.9 (2.6 to 3.2)	0.19 (0.04 to 0.34)
Motor vehicle road injuries	403.6 (373.4 to 442.3)	7.8 (7.2 to 8.6)	437.3 (404.4 to 475.6)	5.4 (5.0 to 5.8)	−1.22 (−1.28 to −1.16)
SDI					
Low SDI	119.8 (102.3 to 138.9)	29.4 (25.9 to 32.9)	187.6 (162.3 to 212.6)	22.6 (20.1 to 25.4)	−0.85 (−0.95 to −0.74)
Low-middle SDI	200.8 (185.2 to 216.2)	20.3 (18.8 to 21.9)	305.3 (283.5 to 329.0)	17.1 (15.9 to 18.4)	−0.56 (−0.68 to −0.43)
Middle SDI	394.3 (374.2 to 416.0)	25.1 (23.8 to 26.4)	427.0 (397.4 to 463.2)	16.4 (15.2 to 17.7)	−1.36 (−1.52 to −1.2)
High-middle SDI	227.5 (216.4 to 239.7)	21.2 (20.2 to 22.3)	173.2 (154.8 to 193.9)	11.3 (10.2 to 12.5)	−2.05 (−2.24 to −1.87)
High SDI	163.7 (160.5 to 166.5)	17.5 (17.1 to 17.8)	101.8 (96.6 to 107.7)	7.8 (7.4 to 8.3)	−2.59 (−2.78 to −2.39)
Regions					
High-income Asia Pacific	7.9 (7.3 to 8.5)	17.1 (16.6 to 17.6)	11.2 (9.4 to 13.1)	3.4 (3.1 to 3.7)	−5.14 (−5.38 to −4.9)
Central Asia	3.5 (3.4 to 3.5)	22.5 (21.7 to 23.3)	1.8 (1.7 to 1.9)	10.2 (9.3 to 11.2)	−2.67 (−3.60 to −1.73)
East Asia	8.3 (7.6 to 8.9)	21.2 (18. 9 to 24.0)	7.9 (6.7 to 9.1)	14.5 (12.3 to 17.1)	−1.21 (−1.44 to −0.99)
South Asia	14.3 (13.8 to 14.7)	16.1 (14.5 to 17.6)	9.8 (8.9 to 10.8)	15.3 (14.0 to 16.7)	−0.17 (−0.35 to 0.00)
Southeast Asia	25.3 (24.9 to 25.7)	26.5 (24.5 to 28.6)	10.0 (9.3 to 10.6)	17.3 (15.4 to 19.2)	−1.35 (−1.55 to −1.15)
Australasia	36.3 (35.6 to 36.9)	16.3 (16.0 to 16. 7)	39.8 (35.5 to 44.4)	5.2 (4.9 to 5.5)	−3.55 (−3.88 to −3.21)
Caribbean	32.4 (26.6 to 38.6)	24.3 (22.4 to 25.9)	51.9 (41.5 to 63.2)	16.1 (13.6 to 18.7)	−1.29 (−1.58 to −1.00)
Central Europe	246.0 (218.5 to 279.0)	19.2 (18.9 to 19.5)	253.7 (211.6 to 301.0)	7.1 (6.6 to 7.5)	−3.03 (−3.41 to −2.65)
Eastern Europe	63.4 (62.4 to 64.1)	26.6 (26.2 to 26.9)	23.2 (21.2 to 25.2)	10.2 (9.3 to 11.0)	−3.61 (−4.71 to −2.5)
Western Europe	40.6 (35.4 to 47.2)	15.8 (15.6 to 15.9)	58.9 (51.3 to 67.0)	3.6 (3.5 to 3.7)	−4.67 (−4.95 to −4.39)
Andean Latin America	31.8 (30.7 to 32.6)	24.7 (22.9 to 26.8)	10.2 (9.3 to 11.0)	17.2 (14.4 to 20.2)	−1.26 (−2.03 to −0.48)
Central Latin America	53.6 (52.7 to 54.4)	26.6 (26.2 to 27.0)	43.3 (41.6 to 44.7)	15.2 (13.6 to 17.0)	−1.83 (−2.22 to −1.43)
Southern Latin America	109.7 (99.9 to 118.5)	13.7 (13.4 to 14.0)	116.4 (103.7 to 129.7)	10.2 (9.8 to 10.6)	−0.90 (−1.34 to −0.45)
Tropical Latin America	1.1 (0.8 to 1.4)	29.4 (28.8 to 30.1)	2.1 (1.8 to 2.6)	16.1 (15.5 to 16.6)	−1.94 (−2.42 to −1.46)
North Africa and Middle East	146.1 (132.5 to 160.1)	36.6 (33.6 to 39.3)	269.9 (247.0 to 294.4)	19.9 (17.8 to 22.1)	−1.95 (−2.04 to −1.85)
High-income North America	111.0 (102.7 to 119.7)	18.1 (17.8 to 18.3)	123.0 (109.1 to 136.7)	10.2 (9.8 to 10.5)	−1.82 (−2.28 to −1.36)
Oceania	6.6 (6.5 to 6.8)	20.8 (15.6 to 25.9)	7.6 (7.3 to 7.9)	17.3 (14.2 to 20.7)	−0.57 (−0.64 to −0.49)
Central Sub-Saharan Africa	21.6 (20.0 to 23.1)	62.5 (52.3 to 73.2)	28.4 (26.1 to 30.8)	47.2 (38.1 to 57.0)	−0.92 (−1.04 to −0.8)
Eastern Sub-Saharan Africa	39.7 (38.7 to 40.6)	31.9 (28.6 to 36.0)	39.9 (38.4 to 41.1)	22.3 (19.8 to 25.3)	−1.16 (−1.25 to −1.07)
Southern Sub-Saharan Africa	66.84 (65.68 to 67.6)	47.6 (44.4 to 50.8)	20.2 (19.2 to 20.8)	36.1 (33.3 to 39.2)	−0.92 (−1.55 to −0.29)
Western Sub-Saharan Africa	41.4 (34.5 to 47.0)	26.6 (23.0 to 29. 9)	66.7 (52.8 to 81.1)	20.2 (16.8 to 23.6)	−0.90 (−0.98 to −0.82)

Notes: The 95 % uncertainty intervals were generated using the 25th and 75th ordered values out of 1000 draws from the posterior distribution.
Joinpoint regression analysis was used for calculating the average annual percent change and 95 % confidence interval. *P*-value less than 0.05 was considered statistically significant. AAPC average annual percent change; ASDR age-standardized mortality rate; CI confidence interval; SDI sociodemographic index.

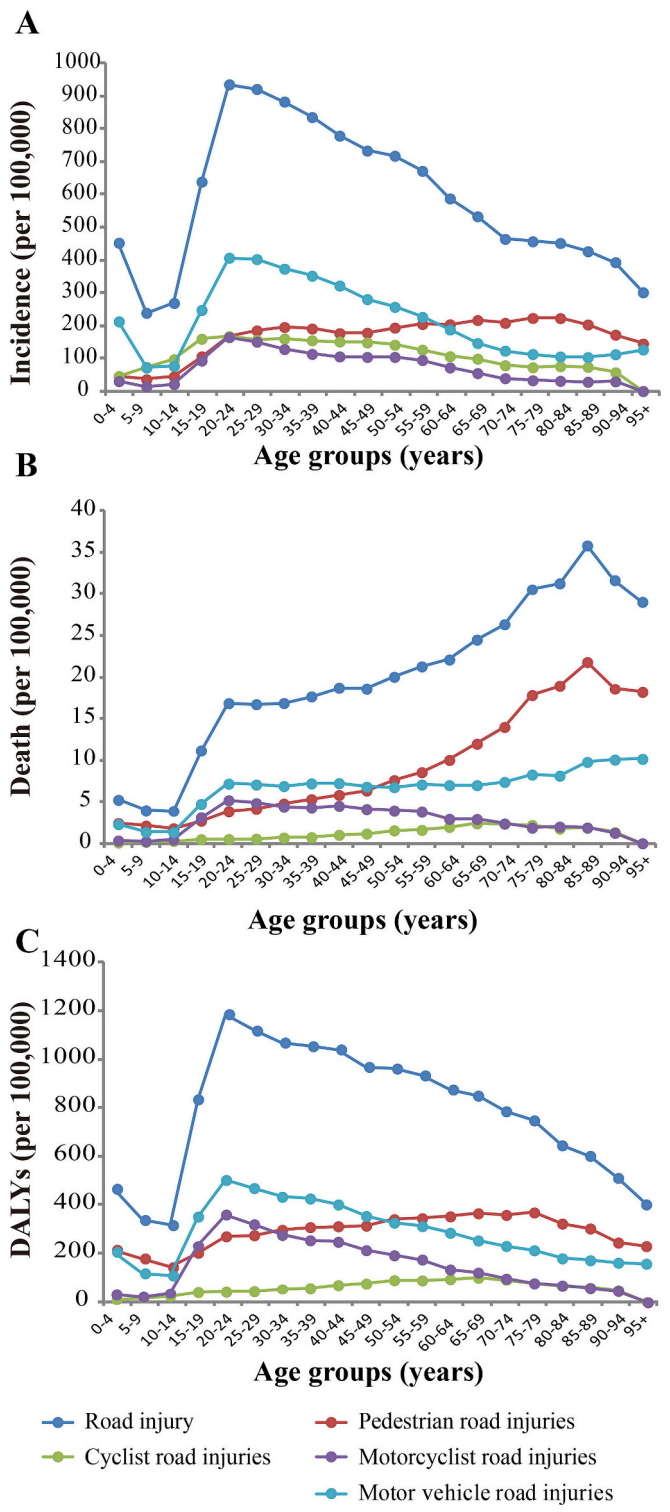

Fig. 1. The burden of road injuries in different age groups in 2021. A. Incidence; B. disability-adjusted life years; C. death. DALYs disability-adjusted life years.

contributor to fatalities (Fig. 1B.). In contrast, the 20–24 age group also had the highest DALYs (1185.3 per 100,000 population), while pedestrian road injuries remained the leading cause of DALYs among older individuals (Fig. 1C.).

3.2. Burden of road injuries in 21 regions

The high-income North America region had the highest ASIR (1162.6 per 100,000 population), and the Eastern Sub-Saharan Africa region had the lowest (1162.6 per 100,000 population) (**Table S1**). The Central Sub-Saharan Africa region had the highest age-standardized DALYs (2435.9 per 100,000 population) and mortality rate (47.2 per 100,000 population), while the high-income Asia Pacific region had the lowest age-standardized DALYs (217.0 per 100,000 population) and mortality rate (3.4 per 100,000 population) (**Table S1 and** Table 1). Except for South Asia, the ASIR in all regions showed a downward trend, and the high-income Asia Pacific region had the most significant decrease in burden. Motor vehicles were the main cause of road injuries in most regions, when the burden of cyclist and motorcyclist road injuries in Asia and America was increased (Fig. 2**.** and Figure **S1**).

3.3. Burden of road injuries in 204 countries and territories

In 2021, Saudi Arabia (2087.2 per 100,000 population), Oman (1909.4 per 100,000 population), and Yemen (1533.2 per 100,000 population) had the highest ASIR, while Bangladesh (167.2 per 100,000 population), Maldives (172.0 per 100,000 population), and Cabo Verde (183.7 per 100,000 population) had the lowest (Figure **S2**). From 1990 to 2021, the absolute number of incident cases increased in more than half of the countries, but the ASIR decreased in most countries.

In 1990, the top three countries with the highest ASDR for road injuries were Oman (94.4 per 100,000 population), Central African Republic (83.9 per 100,000 population), and Angola (71.1 per 100,000 population), while the top three countries with the lowest ASDR were Jamaica (4.0 per 100,000 population), Malta (6.6 per 100,000 population), and Cabo Verde (7.2 per 100,000 population) (Fig. 3A.). In 2021, the Central African Republic (69.6 per 100,000 population), Lesotho (54.7 per 100,000 population), and Eswatini (50.3 per 100,000 population) were the top three countries with the highest ASDR; while Sweden (1.9 per 100,000 population), Singapore (1.9 per 100,000 population), and Malta (1.9 per 100,000 population) were the top three countries with the lowest (Fig. 3B.). From 1990 to 2021, the absolute counts of death increased for 107 countries, and decreased for 97 countries (Fig. 3C.**)**. For the ASDR, 171 countries experienced a decline, 22 countries remained stable, and 11 countries saw an increase (Fig. 3D.).

In 2021, Central African Republic (3764.0 per 100,000 population), Lesotho (2798.4 per 100,000 population), and Eswatini (2596.7 per 100,000 population) had the highest age-standardized DALYs, while Sweden (144.5 per 100,000 population), Singapore (148.5 per 100,000 population), and Norway (150.9 per 100,000 population) had the lowest (Figure **S3**). From 1990 to 2021, the absolute counts of DALYs increased for 94 (46.1 %) counties (Figure **S3**).

3.4. Global burden of road injuries attributable to risk factors

Globally, the deaths from road injuries among males were mainly attributed to occupational injuries (72.2 %), low bone mineral density (21.9 %), and alcohol use (12.7 %); among females, the deaths were mainly attributed to low bone mineral density (57.7 %), occupational injuries (41.4 %), and high temperature (11.0 %) (Fig. 4.). In regions with a high-middle and high SDI, the proportions of deaths and DALYs from road injuries caused by alcohol use and low bone mineral density were relatively high, with sex and regional differences (Fig. 4**.** and **Figure S4**). Notably, the male population in Southern Sub-Saharan Africa experienced the highest burden of road injury deaths attributable to alcohol use (37.0 %). In South Asia, males represented the largest share of road injury deaths attributed to occupational injuries (88.8 %). But females in Western Sub-Saharan Africa faced the greatest burden of road injury deaths due to high temperatures (41.7 %).

Fig. 2. The burden of four common road injuries in different region. A. Age-standardized incidence rate in 2021; B. Average annual percent change of age-standardized incidence rate from 1990 to 2021, C. Age-standardized death rate in 2021; D. Average annual percent change of age-standardized death rate from 1990 to 2021. *P*-values were calculated using Joinpoint regression analysis. $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$.

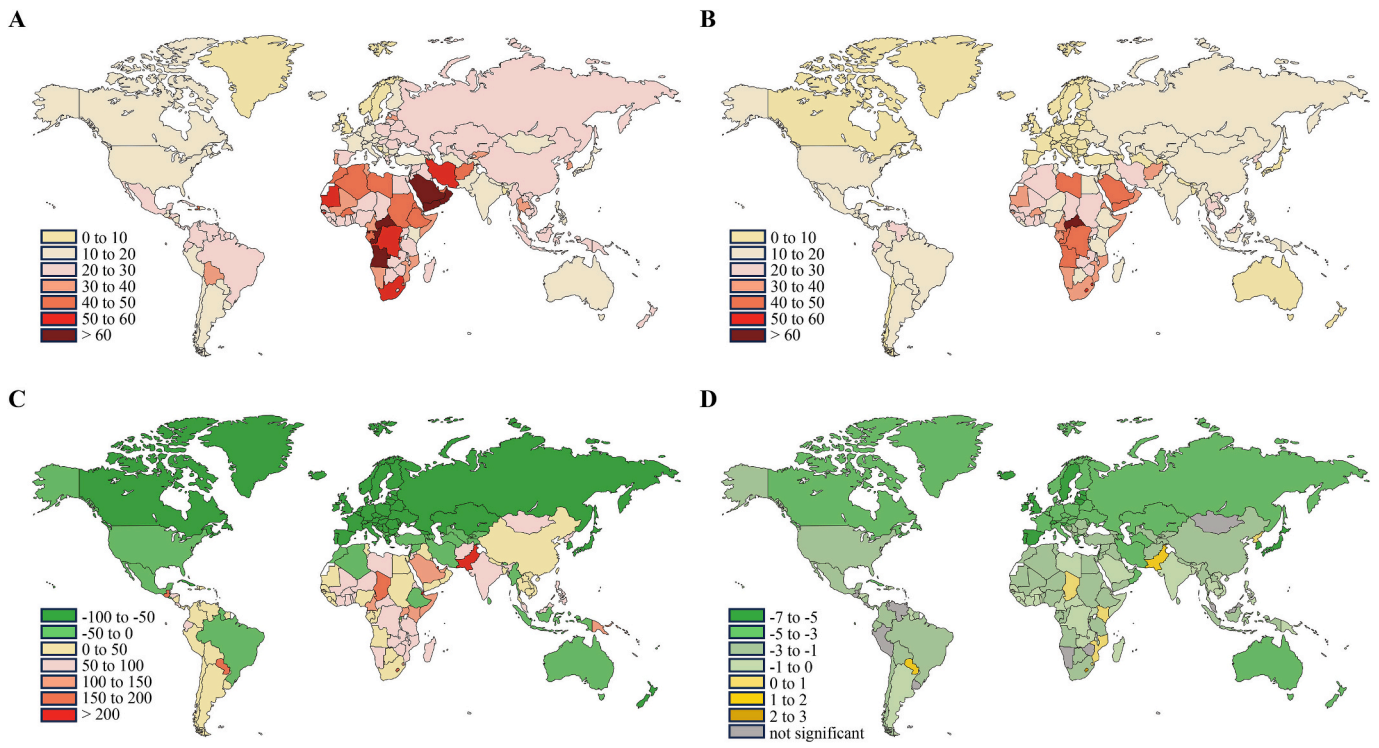

Fig. 3. The age-standardized death rate of road injuries in 204 countries and territories. A. Age-standardized death rate in 1990; B. Age-standardized death rate in 2021; C. Counts changes from 1990 to 2021; D. Average annual percent change of age-standardized death rate from 1990 to 2021.
Joinpoint regression analysis was used for calculating the average annual percent change and 95 % confidence interval. *P*-value less than 0.05 was considered statistically significant.

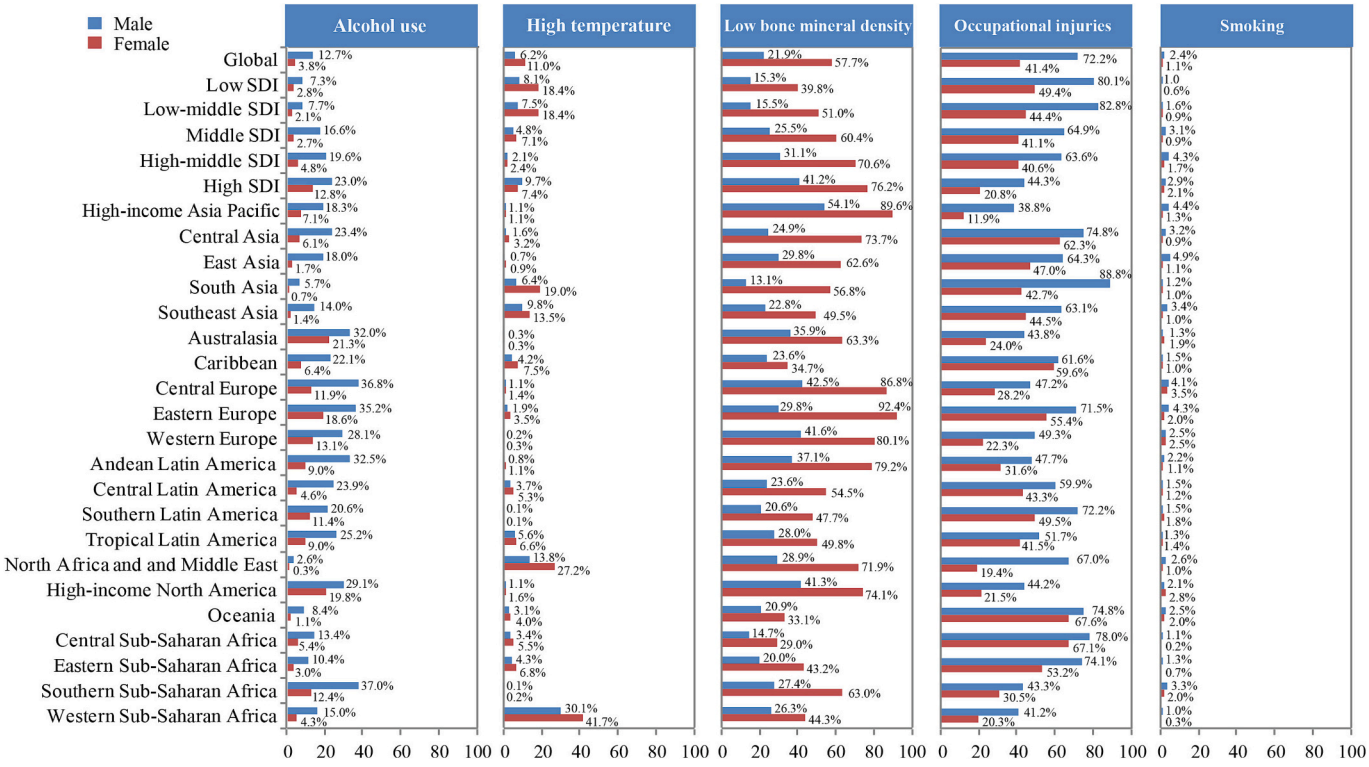

Fig. 4. Road injury-related mortality attributable to the risk factors in 2021.
SDI sociodemographic index.

4. Discussion

Over the past 32 years, although the burden of road injuries has decreased significantly, it remains the 15th leading cause of death globally in 2021. SDG target 3.6 aims to halve the number of road traffic deaths and injuries by 2020. However, in reality, the absolute number of deaths increased by 8 % from 1990 to 2021, reflecting gaps in evidence-based interventions worldwide. There is a significant challenge in the next decade to reduce the global burden of road injuries. Despite the United Nations General Assembly adopting a resolution announcing the second Decade of Action for Road Safety (2021−2030) to reduce both the risk and global burden of road injuries, there remains a significant challenge in the next decade (Hyder et al., 2022). This comprehensive study, based on GBD 2021, will guide future research in specific regions. In India, research could focus on sub-national differences in road injury burdens and the impact of motorization. Regions with rapid motorization, like parts of Southeast Asia and Africa, and those affected by global warming, such as Western Sub-Saharan Africa, should conduct more research to address related road-safety issues.

SDI is a composite indicator based on income per capita, average educational attainment, and total fertility rate in people under 25 years. Our results suggested that the incidence of road injuries in regions with high SDI was twice that of regions with low SDI, the DALYs due to road injuries in regions with low SDI were twice that of regions with high SDI, and the deaths in regions with low SDI were indeed three times that of regions with high SDI. Regional and national levels also suggested that low-income or middle-income countries (such as the Central African Republic, Lesotho, and Eswatini) have a high burden of road injuries, consistent with previous studies (*Global status report on road safety* 2023. Health and Safety, 2023; James et al., 2020; Xu et al., 2022). Developed countries usually have comprehensive road safety laws and regulations, good road conditions, and timely medical assistance, which are effective in reducing road injuries and related deaths.

From 1990 to 2010, pedestrian road injuries were the main cause of death. However, in the last decade, with the increase of motor vehicle ownership, motor vehicle road injuries have also become a primary cause of death. Even worse, the absolute number of deaths resulting from road injuries involving motor vehicles, motorcycles, and cyclists has increased. As suggested by previous research, in Latin America, the rapid motorcycle-oriented motorization has been accompanied by a rise in related road injuries (Martinez et al., 2019); in Asia, countries like Cambodia have also faced traffic problems related to the increasing number of motorcycles (A YK, B MH, C EY, 2018). These regional cases illustrate the potential impact of motor vehicle ownership growth on road safety. Although deaths from pedestrian road injuries were decreased, there still remained the leading cause of death from road injuries. Additionally, there has been a significant upward trend in deaths from motorcyclist road injuries over the past decades. Motorcycle helmets are the most common and effective protective devices for reducing head injuries and fatalities in accidents (Lucci et al., 2021). Motorcycle riders who forgo helmet use face higher in-hospital mortality rates, longer stays in the intensive care unit, and more severe injuries related to motorcycle accidents (Busko et al., 2017; Rosander et al., 2023; Rice et al., 2017). These research findings highlight the importance of wearing helmets. Therefore, global road safety performance targets have been proposed to increase the proportion of motorcycle riders correctly using standard helmets to close to 100 % by 2030 (Hyder et al., 2022).

Motor vehicles were the most common cause of road injuries in most regions. High-income North America had the highest incidence of motor vehicle road injuries, while the related DALYs and deaths were not high. The highest number of deaths and DALYs due to motor vehicle road injuries were in Central Sub-Saharan Africa and Southern Sub-Saharan Africa. Additionally, pedestrian road injuries were the main cause of DALYs and deaths in Central Sub-Saharan Africa. It is noteworthy that the burden is increased in cyclist road injuries in Asia and motorcyclist road injuries in America. In recent years, with the improvement of road construction and the promotion of healthy lifestyles in Asian countries, more and more people have begun participate in cycling activities (Hsieh et al., 2021). Among Asian countries, such as China, India, and Singapore, the overall cycling rates are continuously increasing (Goel et al., 2022). According to the World Health Organization, Colombia obtained the tenth position worldwide and the second in South America (Ospina-Mateus et al., 2020). It was reported that in Bogota, the deaths of motorcyclists on the roads accounted for around 32 % of all road fatalities in 2017 (Ospina-Mateus et al., 2022). Hence, targeted policies and programs need to be developed for different regions.

Road injuries affect individuals of all ages and demographics, with no specific group being immune. Notably, individuals aged 20 to 24 are particularly vulnerable to road injuries, with motor vehicles and motorcycles being the primary causes. Factors such as speeding, driving under the influence, and failure to wear a helmet are significant risk factors (*Global status report on road safety* 2023. Health and Safety, 2023). It is important to highlight that pedestrian road injuries are a major contributor to DALYs and fatalities among older individuals. The Global Status Report on Road Safety 2023 revealed that road injuries were the leading cause of death among children and youth aged 5–29 years in 2019. Alarmingly, two-thirds of these fatalities occur in individuals of working age (18–59 years), resulting in substantial health, social, and economic burdens worldwide.

Occupational injuries, low bone mineral density, alcohol use, and smoking were the risk factors for death or DALYs due to road injuries. Sex and regional differences exist worldwide. Low bone mineral density was primarily responsible for deaths from road injuries in Europe and high-income regions, particularly among females, who were at higher risk of this exposure (Azangou-Khyavy et al., 2022). The highest burden of alcohol use leading to death from road injuries was observed in Europe and some high-income regions, among males. It was reported that 7.52 % of all road injury deaths among males were due to alcohol, while only 1.67 % of female deaths were attributed to alcohol use in 2019 (Borges et al., 2021). However, in 2021, these proportions increased to 12.7 % for males and 3.8 % for females, indicating that drink-driving remains a major risk factor for road traffic accidents. Despite considerable efforts to combat drunk driving, there is still a long way to go. Additionally, road injury deaths caused by high temperatures predominantly occur in tropical regions such as Western Sub-Saharan Africa, North Africa and Middle East, especially affecting females. Numerous studies have investigated the relationship between ambient temperature and road safety (He et al., 2023; Liang et al., 2022; Theofilatos and Yannis, 2014). High temperatures have varying effects depending on the region, mode of transportation, and demographic factors. Motor vehicles face an increased risk of collisions, as elevated temperatures can impair their mechanical performance; motorcycle riders are particularly vulnerable to the effects of high temperatures due to their exposure, while cyclists also face a heightened risk of injury in such conditions (Liu et al., 2017; Zare Sakhvidi et al., 2022; Zhu et al., 2024). Additionally, ambient temperature influences road injuries differently across age groups, and these effects vary between temperate and tropical regions (Zhu et al., 2024; Liang et al., 2021). Furthermore, extreme temperatures are associated with occupational road injuries, as they can elevate the accident risk for professional drivers (Zhu et al., 2024; Gariazzo et al., 2021).

Some limitations need to be addressed. Firstly, our study has limitations common to all GBD studies. Many countries, especially low- and middle-income ones, lack reliable epidemiological data. As a result, country estimates rely on predictive covariates and data from neighboring countries. Secondly, differences in injury reporting systems across countries may lead to underreporting, particularly in low-SDI regions, potentially resulting in an underestimation of road injuries. Moreover, other data-collection-related issues, such as the higher likelihood of underreporting certain injuries associated with specific modes of transportation, may also introduce bias into the data. Thirdly, the

analysis relies on yearly data, and considering that finer-grained data (e.g., daily or monthly) could provide more detailed insights and support richer conclusions, future research should focus on using higher resolution data. Finally, our results are influenced by biases presented in the original research. Before the COVID-19 pandemic, road injuries were the 12th leading cause of death in 2019. However, in 2021, road injuries fell to the 15th, likely due to people staying home during the pandemic. Consequently, the burden of road injuries may increase again in the near future.

5. Conclusion

Road safety continues to be a major global public health concern. Despite a notable decrease in the burden of road injuries over the past 32 years, the world has yet to achieve the SDG targets. Male populations and some low-income countries like the Central African Republic face a high burden. Young people aged 20–24 years are particularly susceptible to road injuries, with a higher risk of being involved in motor vehicle and motorcyclist-related accidents. In contrast, the elderly population, specifically those aged 85–89 years, are predominantly affected by pedestrian road injuries. Importantly, this study has identified the risk factors contributing to the deaths and DALYs associated with road injuries. The findings of this research will facilitate developing evidence-based strategies aimed at improving road safety and reducing the associated burden.

CRediT authorship contribution statement

Dongqing Gu: Writing – original draft, Methodology, Formal analysis, Data curation. **Shan Ou:** Writing – original draft, Validation, Methodology, Formal analysis, Data curation. **Guodong Liu:** Writing – review & editing, Validation, Project administration.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pmedr.2025.103051.

Data availability

The data were obtained from GBD 2021 using the online Global Health Data Exchange query tool (https://vizhub.healthdata.org/gbd-results/)

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