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Global trends in chronic kidney disease mortality and disability-adjusted life years attributable to low physical activity (1990–2021): a growing public health challenge

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Abstract

Background Low physical activity (LPA) is a major contributor to the global burden of chronic kidney disease (CKD). Our goal was to assess the spatiotemporal trends in the CKD burden attributable to LPA from 1990 to 2021, with a focus on the globe, China, five SDI regions, and four continents.

Methods We analysed CKD-related deaths, DALYs, the ASMR, the ASDR, and the EAPC attributable to low physical activity (LPA). This study focused on trends from 1990 to 2021 across the globe, China, five SDI regions, and four continents. Decomposition analysis, frontier analysis, and forecasting models were employed to explore changes in these indicators and their influencing factors.

Results In 2021, CKD attributable to low physical activity (LPA) resulted in 913,070 [95% UI: 348,170–1,619,770] DALYs and 40,920 [95% UI: 16,170–72,560] deaths globally, both of which were higher than those reported in 1990. The AOSD increased from 9.63 (95% UI: 3.73–17.02) to 10.81 (95% UI: 4.14–19.18) per 100,000, with an EAPC of 0.42 (95% CI: 0.35–0.48). The ASMR increased from 0.42 (95% UI: 0.17–0.74) to 0.50 (95% UI: 0.20–0.90) per 100,000, with an EAPC of 0.65 (95% CI: 0.57–0.73). The burden was greater among females, with more rapid increases in the ASDR and ASMR. The Americas and high-SDI regions presented the greatest growth in DALY and mortality rates.

Conclusions The burden of CKD attributable to low physical activity (LPA) has increased significantly, particularly in low-SDI regions, women, and elderly individuals. The findings highlight the importance of promoting physical activity and implementing early interventions to inform public health policies.

Clinical trial number Not applicable.

Keywords Low physical activity, Chronic kidney disease, Disease burden, Disability-adjusted life years, Mortality, Socio-Demographic index

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Introduction

Chronic kidney disease (CKD) is a group of disorders that impair kidney function, and its burden is increasing globally [1]. Between 1990 and 2019, the number of CKD cases increased from 7.8 million to 18.99 million, whereas disability-adjusted life years (DALYs) rose from 21.5 million to 41.54 million [2]. According to estimates from the Global Burden of Disease (GBD) 2021 [3], the increasing CKD burden is closely associated with population aging, unhealthy lifestyles, and the cumulative effects of chronic diseases. In recent years, low physical activity has become a major risk factor for noncommunicable diseases (NCDs), contributing to the increased incidence of various chronic conditions, including diabetes, cardiovascular diseases, and CKD.

Previous studies have shown that low levels of physical activity significantly increase the risk of chronic kidney disease (CKD) and end-stage renal disease (ESRD) associated with diabetes and hypertension [4, 5]. Physical activity may influence the onset and progression of CKD through multiple pathophysiological mechanisms, including inflammatory responses, oxidative stress, vascular dysfunction, immune imbalance, and metabolic dysregulation of macromolecules [6]. Furthermore, existing evidence indicates that regular exercise effectively improves these pathophysiological conditions [7]. Systematic reviews have demonstrated that increasing physical activity levels effectively reduces the risk of these chronic diseases [8].

The World Health Organization (WHO) recommends that adults engage in at least 150 min of moderate-intensity physical activity, 75 min of vigorous-intensity activity per week, or an equivalent combination. However, according to recent WHO data, 31% of adults worldwide do not meet these recommended levels, with the proportion expected to rise to 35% by 2030 [9]. The growing burden of chronic diseases related to low physical activity is evident not only in low- and middle-income countries but also in high-income countries [10].

Previous studies have explored the global and regional impacts of low physical activity on disease burden. In 2019, Roth et al. assessed the global burden of cardiovascular diseases (CVDs) and their associated risk factors but did not conduct a detailed analysis by country or specific etiology [11]. Similarly, Xu et al. investigated the global impact of low physical activity via the GBD database, revealing its increasing contribution to several chronic diseases but without specifically examining its burden on CKD [12]. Research on trends in CKD burden attributable to low physical activity across different socioeconomic levels and regions remains limited.

Therefore, this study, which is based on the latest GBD 2021 data, focuses on evaluating the burden of CKD attributable to low physical activity (LPA) from 1990 to 2021. The analysis covers mortality and disability-adjusted life years (DALYs) across global, national (China), and sociodemographic index (SDI) quintiles and across four continents. The specific objectives are (1) to track the long-term trends of CKD burden caused by low physical activity over the past three decades; (2) to compare the differences in CKD burden across global, national, and SDI quintiles and across continental levels; (3) to analyse the burden distribution by sex and across age groups from 25 to 95 years; and (4) to compare the changes in the burden caused by different etiologies between 1990 and 2021. The findings of this study highlight the significant role of low physical activity in increasing the CKD burden and provide essential data to support the development of global and regional public health policies aimed at mitigating this growing burden.

Materials and methods

Data source

The data for this study were sourced from GBD 2021. GBD 2021 provides the latest and most comprehensive assessment of 369 diseases and 87 associated risk factors globally, covering data from 1990 to 2021. This study examined the impact of low physical activity on the burden of chronic kidney disease (CKD), including data on deaths, age-standardized mortality rates (ASMRs), disability-adjusted life years (DALYs), and age-standardized DALY rates (ASDRs), all of which were obtained from an online data platform (https://vizhub.healthdata.org/gbd-results/).

To further elucidate the relationship between the burden of CKD attributable to low physical activity and the developmental status of individual countries, we employed the sociodemographic index (SDI). The SDI is a composite metric designed to reflect the developmental status of countries, incorporating dimensions such as income, educational attainment, and fertility rates, all of which are closely linked to health outcomes. Data on the SDI for the 21 regions covered in the Global Burden of Disease (GBD) 2021 study were obtained from the Institute for Health Metrics and Evaluation (https://ghdx.healthdata.org/record/ihme-data/gbd-2021-sociodemographic-index-sdi-1990-2021). The use of this composite me asure facilitates a more comprehensive understanding of the complex relationship between socioeconomic development levels and the burden of CKD, thereby providing a basis for the formulation of more targeted public health intervention strategies.

Definitions

Chronic kidney disease classification

According to the International Classification of Diseases (ICD), chronic kidney disease (CKD) can be classified into the following primary categories: glomerular diseases, tubulointerstitial nephritis, diabetic nephropathy, hypertensive nephropathy, polycystic kidney disease, and various other renal disorders [13]. CKD is coded via the ICD-10 classification system.

Sociodemographic Index (SDI)

The sociodemographic index (SDI) is used to categorize countries and regions into five groups. It is calculated by combining three key indicators: average years of education, per capita income, and total fertility rate. The SDI serves as a measure of national development, ranging from 0 (lowest) to 1 (highest). The five categories are defined as follows: high SDI (> 0.81), upper-middle SDI (0.70–0.81), middle SDI (0.61–0.69), lower-middle SDI (0.46–0.60), and low SDI (≤ 0.46). These classifications are used to group countries into 21 geographical regions as defined by the global burden of disease (GBD) framework [14].

Physical activity measurement

In the Global Burden of Disease (GBD) study, physical activity is measured among individuals aged 25 and older, covering activities lasting at least ten minutes in different settings, such as leisure, work, household tasks, and transportation. This study uses the metabolic equivalent of task (MET), which is the ratio of energy expended during an activity to resting energy expenditure. On the basis of total weekly MET minutes, physical activity is classified as inactive (< 600 MET-minutes/week), low (600–3,999 MET-minutes/week), moderate (4,000–7,999 MET-minutes/week), or high (≥ 8,000 MET-minutes/week). Ideally, the minimum recommended level is 3,000–4,500 MET-minutes per week, with low physical activity (LPA) defined as < 3,000 MET-minutes per week [15].

Burden of disease assessment

According to the Global Burden of Disease (GBD) study, disability-adjusted life years (DALYs) are a key metric for assessing the impact of chronic kidney disease (CKD) on global and regional population health. The GBD provides time series data from 1990 to 2021, allowing researchers to analyse trends and regional differences and identify high-risk areas to support health policy decisions. The study also highlights the relationship between CKD burden and socioeconomic development levels, such as the sociodemographic index (SDI), offering insights into the disease's distribution across different social contexts.

Estimation methods

Estimation of the annual percentage change (EAPC)

This study uses the estimated annual percentage change (EAPC) to assess the average yearly trend of specific health indicators over the study period. The EAPC is determined by applying a linear regression model to the log-transformed values of the health indicator. In this model, the year serves as the independent variable, whereas the log-transformed health indicator is the dependent variable. The slope of the regression line reflects the logarithmic rate of change.

The EAPC is calculated via the following formula:

$\text{EAPC} = (e^b - 1) \times 100\%$.

where b is the slope coefficient obtained from the linear regression. The exponential function e^b converts the slope from a logarithmic scale to a percentage change [16].

By computing the EAPC along with its 95% confidence interval (CI), this study enables comparisons of health trends across regions or time periods. A positive EAPC indicates a rising trend, a negative EAPC suggests a declining trend, and an EAPC close to zero reflects a stable trend.

AutoRegressive Integrated Moving Average (ARIMA) models

This study used ARIMA models to forecast CKD mortality and deaths due to low physical activity for 2021–2031 [17], based on historical trends from the Global Burden of Disease (GBD) 2021. Following the Box–Jenkins method, parameters were identified through autocorrelation (ACF) and partial autocorrelation (PACF) plots. The best model was selected using the Akaike information criterion (AIC) and Bayesian information criterion (BIC), with parameter estimation performed via maximum likelihood. The Ljung–Box Q test verified the accuracy of residuals. Finally, predicted and observed values were compared, and 95% confidence intervals (CIs) as well as prediction intervals (PIs) were generated to account for uncertainty [18].

Decomposition analysis

This study employs decomposition analysis to quantify the contributions of population growth, population aging, and ASR (age-standardized incidence rate) changes to the burden of chronic kidney disease (CKD) caused by low physical activity. The key variables are N_1 and N_2, representing the population size at two time points; s_{i1} and s_{i2}, indicating the proportion of each age group; and m_{i1} and m_{i2}, reflecting the incidence rates.

Decomposition Formulas:

Population growth:

$$Mp = \sum (N_2 - N_1)\, s_{i1}\, m_{i1}$$

Population aging:

$$Ma = \sum N_1\, (s_{i2} - s_{i1})\, m_{i1}$$

ASR Change:

$$Mm = \sum N_1\, s_{i1}\, (m_{i2} - m_{i1})$$

Interaction Effects:

Two-way interactions:

$I_{pa} = \Sigma\,(N_2 - N_1)\,(s_{i2} - s_{i1})\,m_{i1}$

$I_{pm} = \Sigma\,(N_2 - N_1)\,s_{i1}\,(m_{i2} - m_{i1})$

$I_{am} = \Sigma\,N_1\,(s_{i2} - s_{i1})\,(m_{i2} - m_{i1})$

Three-way Interaction:

$I_{pam} = \Sigma\,(N_2 - N_1)\,(s_{i2} - s_{i1})\,(m_{i2} - m_{i1})$

These formulas allow for a comprehensive evaluation of individual and combined influences, clarifying how changes in population dynamics and health indicators shape the CKD burden over time [19].

Frontier analysis

Frontier analysis is used to evaluate the performance of countries or regions in reducing the burden of chronic kidney disease (CKD) caused by low physical activity relative to their sociodemographic development level (measured by the sociodemographic index (SDI)). The frontier represents leading countries with the lowest disease burden. The effective difference is the gap between a country's current burden and the frontier's burden, highlighting improvement opportunities. Countries far from the frontier have the potential to reduce the CKD burden on the basis of their development level [20].

Statistical analysis

This study evaluated the disease burden of chronic kidney disease (CKD) caused by low physical activity at the global level in China across five social development index (SDI) regions and four continents. The evaluation included metrics such as the number of deaths, age-standardized mortality rate (ASMR), disability-adjusted life years (DALYs), and age-standardized DALYs (ASDR). Additionally, the study areas were stratified by region and age into different groups and 15 age cohorts. Each metric is presented with uncertainty intervals (UIs), which are determined by drawing 1,000 samples from the posterior distribution and using the 25th and 975th ordered values to establish the range.

This study analysed the relationship between the SDI and age-standardized rates (ASRs) from 1990 to 2021. On the basis of the SDI in 2021, which reflects social development and health status, and the baseline disease burden represented by the ASR in 1990, the 2021 Human Development Index (HDI) can reflect the level of health resources across countries. All the statistical analyses were conducted via R software (Chinese version, version 4.4.1), with $P < 0.05$ indicating statistical significance.

Results

Global burden of Chronic Kidney Disease (CKD) due to physical inactivity

Globally, the number of deaths due to chronic kidney disease (CKD) attributable to physical inactivity increased by 197.21% from 1990 to 2021. The increase in females (200.39%) was slightly greater than that in males (193.18%). In 2021, the number of female deaths was 22,920 (95% UI: 9,020–40,810), which was greater than that of male deaths at 17,990 (95% UI: 7,150–31,820). The estimated annual percentage change (EAPC) of deaths globally was 0.65 (95% CI: 0.57–0.73), with a higher EAPC for females (0.71, 95% CI: 0.61–0.82) than for males (0.49, 95% CI: 0.44–0.55) (Fig. 1; Table 1).

Similarly, the disability-adjusted life years (DALYs) due to CKD attributable to physical inactivity increased by 156.60% from 1990 to 2021. The increase in females (158.85%) was greater than that in males (153.99%). In 2021, the DALY for females was 9.63 per 100,000 people (95% UI: 3.73–17.02), which was higher than that for males at 7.15 per 100,000 people (95% UI: 2.64–12.71). The global EAPC of DALYs was 0.42 (95% CI: 0.35–0.48), with an EAPC of 0.49 (95% CI: 0.41–0.57) for females and 0.30 (95% CI: 0.26–0.34) for males (Table 1).

Regional burden of CKD attributable to physical inactivity in different SDI regions

The increase was highest in low-SDI regions, with deaths increasing by 103.26% and DALYs increasing by 101.68%. The increase for females (132.56%) was greater than that for males (76.00%). In 2021, the number of female deaths was 1,000 (95% UI: 360–1,840), whereas the number of male deaths was 880 (95% UI: 310–1,630). The EAPC of deaths in low-SDI regions was − 0.32 (95% CI: -0.45–0.19), with an EAPC of -0.06 (95% CI: -0.19–0.07) for females and − 0.56 (95% CI: -0.69– -0.43) for males (Table 1).

The burden increased the least in high-SDI regions, with deaths increasing by 234.48% and DALYs increasing by 161.05%. Males presented a greater growth rate for both indicators than females did. In 2021, the number of female deaths was 6,680 (95% UI: 2,640–12,250), whereas the number of male deaths was 4,960 (95% UI: 2,020–8,820). The EAPC of deaths in high-SDI regions was 1.39 (95% CI: 1.27–1.51), with an EAPC of 1.39 (95% CI: 1.21–1.57) for females and 1.21 (95% CI: 1.11–1.31) for males.

In middle-SDI regions, the number of deaths increased from approximately 43,500 (95% UI: 17,000–74,800) in 1990 to 138,300 (95% UI: 52,700–242,800) in 2021, representing a growth of approximately 218%. Although the increase in deaths was significant, the overall EAPC was 0.15 (95% CI: 0.09–0.22). The EAPC for females was − 0.04 (95% CI: -0.09–0.01), whereas for males, it was 0.4

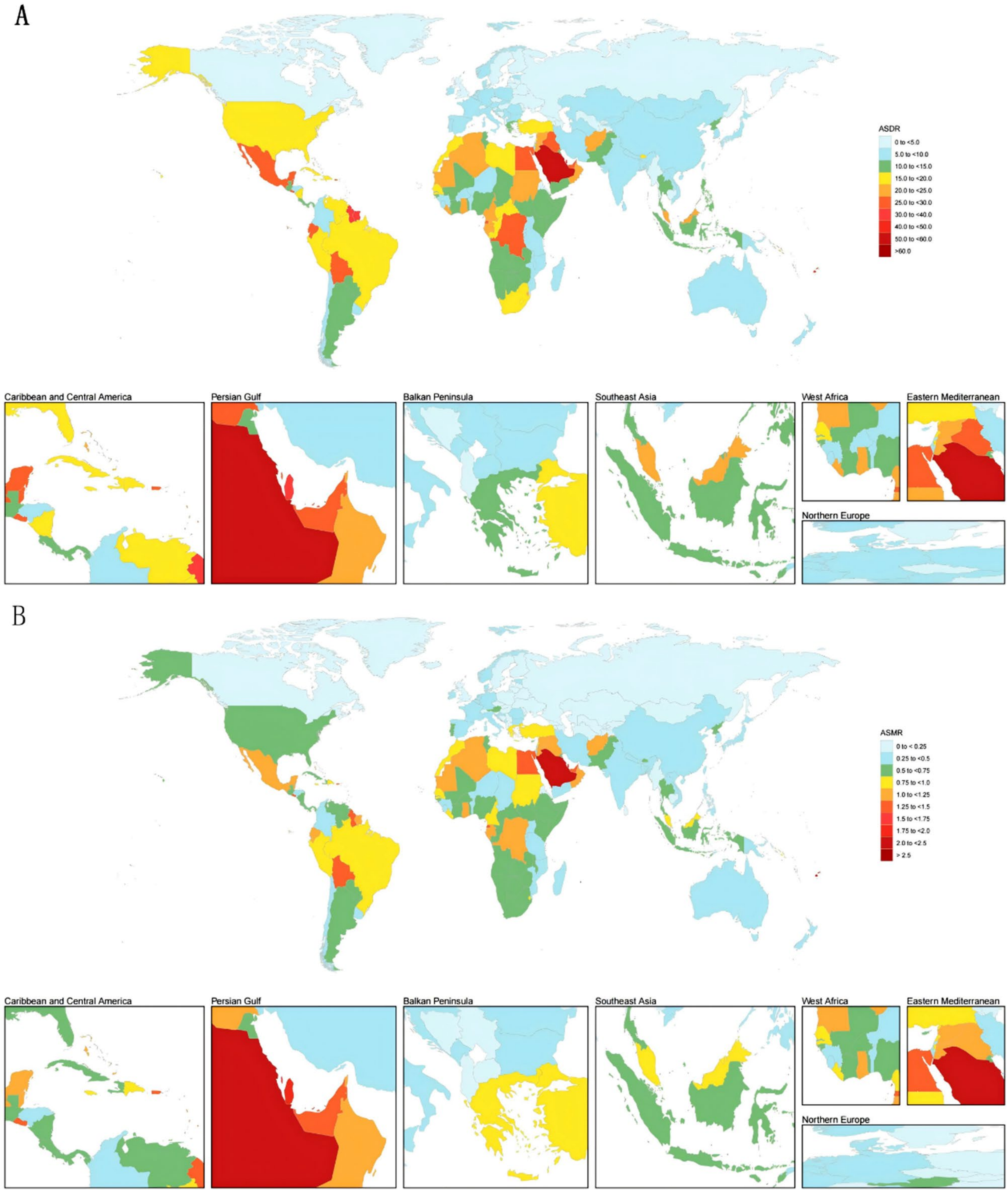

Fig. 1 Global distribution of chronic kidney disease (CKD) burden attributable to low physical activity in 2021. (**A**) Deaths, (**B**) ASDR, and (**C**) ASMR. Abbreviations: ASMR = age-standardized mortality rate; ASDR = age-standardized DALY rate; DALY = disability-adjusted life year

Table 1 Deaths, the dalys and their corresponding ASRs in 1990 and 2021 and the EAPC in the ASRs from1990 to 2021

Location	Sex	DALYs					Deaths				
		No. × 10^3 (95% UI) in 1990	Age-standardized no. × 10^−5 (95% UI) in 1990	No. × 10^3 (95% UI) in 2021	Age-standardized no. × 10^−5 (95% UI) in 2021	EAPC (95% CI) (1990–2021)	No. × 10^3 (95% UI) in 1990	Age-standardized no. × 10^−5 (95% UI) in 1990	No. × 10^3 (95% UI) in 2021	Age-standardized no. × 10^−5 (95% UI) in 2021	EAPC (95% CI) (1990–2021)
Global	Both	355.84 (137.25,622.35)	9.63 (3.73,17.02)	913.07 (348.17,1619.77)	10.81 (4.14,19.18)	0.42 (0.35,0.48)	13.77 (5.37,24.41)	0.42 (0.17,0.74)	40.92 (16.17,72.56)	0.5 (0.2,0.9)	0.65 (0.57,0.73)
	Female	195.27 (77.13,346.67)	9.5 (3.79,16.92)	505.4 (190.83,885.37)	10.95 (4.13,19.19)	0.49 (0.41,0.57)	7.63 (3.09,13.43)	0.4 (0.16,0.7)	22.92 (9.02,40.81)	0.49 (0.19,0.87)	0.71 (0.61,0.82)
	Male	160.56 (60.95,290.1)	10.01 (3.76,17.99)	407.67 (152.87,727.91)	10.77 (4.07,19.26)	0.3 (0.26,0.34)	6.14 (2.27,10.82)	0.47 (0.18,0.83)	17.99 (7.15,31.82)	0.53 (0.21,0.94)	0.49 (0.44,0.55)
Africa	Both	39.8 (14.53,74.85)	15.37 (5.75,28.57)	98.57 (33.73,181.66)	15.93 (5.56,29.41)	0.02 (-0.03,0.07)	1.52 (0.56,2.91)	0.72 (0.27,1.35)	3.75 (1.32,6.86)	0.76 (0.28,1.4)	0.11 (0.05,0.18)
	Female	20.68 (7.76,36.64)	15.63 (5.93,27.57)	56.83 (19.82,105.44)	17.41 (6.17,32.19)	0.28 (0.24,0.32)	0.78 (0.29,1.4)	0.71 (0.27,1.29)	2.14 (0.76,3.94)	0.82 (0.3,1.49)	0.41 (0.36,0.46)
	Male	19.12 (6.61,36.01)	15.1 (5.2,28.54)	41.73 (14.21,77.36)	14.27 (5.03,26.15)	-0.3 (-0.37,-0.24)	0.75 (0.26,1.41)	0.73 (0.26,1.42)	1.61 (0.58,2.93)	0.7 (0.26,1.26)	-0.26 (-0.35,-0.17)
America	Both	66.03 (25.06,116.86)	10.97 (4.19,19.44)	221.87 (84.12,384.49)	16.57 (6.27,28.82)	1.45 (1.25,1.65)	2.71 (1.04,4.77)	0.46 (0.18,0.82)	10.35 (3.91,18.02)	0.75 (0.28,1.3)	1.7 (1.46,1.93)
	Female	35.37 (13.26,63.05)	10.4 (3.89,18.62)	118.14 (44.63,206.72)	16.11 (6.04,28.08)	1.49 (1.21,1.78)	1.48 (0.56,2.63)	0.43 (0.16,0.76)	5.6 (2.08,9.71)	0.71 (0.26,1.22)	1.76 (1.43,2.09)
	Male	30.66 (11.73,53.6)	11.92 (4.6,20.72)	103.73 (39.95,181.36)	17.27 (6.65,30.12)	1.34 (1.22,1.47)	1.23 (0.47,2.12)	0.53 (0.2,0.91)	4.75 (1.9,8.18)	0.81 (0.32,1.4)	1.53 (1.38,1.67)
Asia	Both	189.24 (73.35,333.23)	10.47 (4.16,18.49)	485.56 (185.82,859.16)	10.01 (3.86,17.74)	-0.15 (-0.22,-0.08)	7.13 (2.85,12.45)	0.48 (0.2,0.83)	20.93 (8.37,37.4)	0.47 (0.19,0.84)	-0.11 (-0.18,-0.05)
	Female	103.05 (40.01,179.78)	10.85 (4.29,19.09)	264.32 (99.28,458.33)	10.16 (3.81,17.65)	-0.25 (-0.32,-0.19)	3.94 (1.59,6.84)	0.49 (0.2,0.85)	11.39 (4.49,20.2)	0.45 (0.18,0.81)	-0.34 (-0.4,-0.27)
	Male	86.19 (33.34,158.4)	10.11 (3.9,18.3)	221.24 (82.53,398)	9.99 (3.71,17.92)	0 (-0.08,0.09)	3.19 (1.23,5.66)	0.48 (0.19,0.85)	9.54 (3.63,16.94)	0.5 (0.19,0.88)	0.2 (0.12,0.29)
Europe	Both	59.31 (22.66,106.96)	5.89 (2.24,10.67)	104.14 (38.92,188.31)	6.03 (2.24,10.88)	0.24 (0.17,0.31)	2.35 (0.92,4.24)	0.24 (0.09,0.44)	5.73 (2.2,10.51)	0.3 (0.11,0.55)	1.02 (0.87,1.16)
	Female	35.46 (13.51,63.81)	5.63 (2.14,10.18)	64.6 (24.93,116.48)	6.2 (2.33,11.25)	0.46 (0.39,0.53)	1.41 (0.54,2.56)	0.22 (0.08,0.39)	3.71 (1.45,6.85)	0.3 (0.12,0.55)	1.39 (1.24,1.55)
	Male	23.86 (9.01,43.42)	6.64 (2.5,12.04)	39.53 (14.73,72.2)	5.86 (2.18,10.74)	-0.26 (-0.33,-0.19)	0.94 (0.35,1.75)	0.31 (0.12,0.57)	2.02 (0.76,3.7)	0.3 (0.11,0.55)	0.17 (0.02,0.31)
High-middle SDI	Both	72.29 (28.15,126.05)	8.02 (3.14,14.17)	160.5 (62.86,280.58)	8.26 (3.23,14.47)	0.13 (0.02,0.24)	2.84 (1.12,5.01)	0.36 (0.14,0.64)	7.62 (3.05,13.45)	0.4 (0.16,0.71)	0.38 (0.26,0.5)
	Female	41.81 (16.8,73.07)	7.82 (3.14,13.79)	94.5 (35.94,163.51)	8.51 (3.21,14.78)	0.29 (0.17,0.42)	1.63 (0.67,2.91)	0.33 (0.13,0.58)	4.54 (1.82,8.01)	0.39 (0.16,0.69)	0.61 (0.49,0.73)
	Male	30.48 (11.51,55.99)	8.72 (3.38,15.73)	66 (25.44,116.14)	8.11 (3.09,14.3)	-0.19 (-0.3,-0.08)	1.21 (0.46,2.19)	0.44 (0.17,0.78)	3.08 (1.17,5.41)	0.42 (0.16,0.74)	-0.08 (-0.22,0.05)
High SDI	Both	81.32 (31.19,143.59)	7.4 (2.86,13.15)	212.24 (84.15,374.14)	9.75 (3.75,17.16)	1.03 (0.94,1.11)	3.48 (1.34,6.17)	0.32 (0.12,0.56)	11.64 (4.6,20.82)	0.46 (0.18,0.82)	1.39 (1.27,1.51)

Table 1 (continued)

Location	Sex	DALYs					Deaths				
		No. × 10^3 (95% UI) in 1990	Age-standardized no. × 10^−5 (95% UI) in 1990	No. × 10^3 (95% UI) in 2021	Age-standardized no. × 10^−5 (95% UI) in 2021	EAPC (95% CI) (1990–2021)	No. × 10^3 (95% UI) in 1990	Age-standardized no. × 10^−5 (95% UI) in 1990	No. × 10^3 (95% UI) in 2021	Age-standardized no. × 10^−5 (95% UI) in 2021	EAPC (95% CI) (1990–2021)
	Female	47.31 (18.24,82.7)	7.17 (2.79,12.61)	116.23 (45.72,208.39)	9.55 (3.67,16.74)	1.06 (0.95,1.18)	2.1 (0.81,3.76)	0.3 (0.12,0.54)	6.68 (2.64,12.25)	0.43 (0.17,0.78)	1.39 (1.21,1.57)
	Male	34.01 (12.48,61.11)	7.96 (2.93,14.17)	96.01 (37.95,168.06)	10.15 (3.97,17.85)	0.91 (0.8,1.03)	1.37 (0.52,2.42)	0.36 (0.13,0.64)	4.96 (2.02,8.82)	0.5 (0.2,0.89)	1.21 (1.11,1.31)
Low-middle SDI	Both	60.01 (22.54,107.95)	10.77 (4.04,19.46)	158.02 (56.47,290.25)	11.41 (4.09,20.81)	0.18 (0.12,0.25)	2.17 (0.83,4.01)	0.46 (0.18,0.84)	5.91 (2.2,10.6)	0.49 (0.18,0.87)	0.18 (0.12,0.24)
	Female	30.36 (11.72,55.12)	10.98 (4.2,19.74)	88.83 (32.56,162.18)	12.17 (4.46,22.08)	0.34 (0.28,0.4)	1.09 (0.42,1.91)	0.46 (0.18,0.82)	3.28 (1.22,5.85)	0.5 (0.19,0.9)	0.25 (0.18,0.31)
l	Male	29.65 (10.59,54.23)	10.56 (3.73,19.36)	69.18 (23.97,127)	10.61 (3.74,19.43)	0 (-0.07,0.07)	1.08 (0.39,2.01)	0.46 (0.17,0.87)	2.63 (0.95,4.81)	0.47 (0.18,0.86)	0.12 (0.05,0.19)
Low SDI	Both	24.85 (9.22,46.27)	12.11 (4.62,22.16)	50.12 (17.45,93.33)	10.64 (3.74,19.84)	-0.49 (-0.58,-0.41)	0.92 (0.34,1.71)	0.54 (0.2,0.99)	1.87 (0.65,3.46)	0.49 (0.18,0.91)	-0.32 (-0.45,-0.19)
	Female	12.01 (4.66,21.44)	11.7 (4.6,21.23)	27.11 (9.81,50.62)	11.1 (4.05,20.57)	-0.26 (-0.35,-0.17)	0.43 (0.17,0.77)	0.5 (0.2,0.91)	1 (0.36,1.84)	0.5 (0.18,0.93)	-0.06 (-0.19,0.07)
	Male	12.84 (4.67,23.63)	12.51 (4.5,23.05)	23.02 (7.82,42.53)	10.16 (3.51,18.81)	-0.73 (-0.8,-0.65)	0.5 (0.18,0.93)	0.59 (0.22,1.09)	0.88 (0.3,1.63)	0.48 (0.17,0.89)	-0.56 (-0.69,-0.43)
Middle SDI	Both	116.96 (44.41,206.43)	12.43 (4.75,21.92)	331.35 (124.78,590)	12.83 (4.81,22.67)	0.14 (0.06,0.22)	4.35 (1.7,7.48)	0.57 (0.23,0.97)	13.83 (5.27,24.28)	0.59 (0.23,1.04)	0.15 (0.09,0.22)
	Female	63.57 (24.86,111.76)	12.76 (5,22.39)	178.26 (66.04,310.21)	12.88 (4.78,22.44)	0.01 (-0.06,0.08)	2.38 (0.94,4.16)	0.56 (0.23,0.97)	7.4 (2.87,12.89)	0.57 (0.22,0.99)	-0.04 (-0.09,0.01)
	Male	53.39 (20.1,97.71)	12.22 (4.66,21.97)	153.09 (55.32,272.74)	12.94 (4.84,23.18)	0.3 (0.2,0.4)	1.97 (0.75,3.48)	0.59 (0.22,1.02)	6.43 (2.51,11.42)	0.63 (0.25,1.14)	0.4 (0.3,0.49)
China	Both	78.75 (31.19,141.58)	11.04 (4.45,19.52)	189.1 (72.23,332.76)	9.43 (3.59,16.48)	-0.56 (-0.72,-0.4)	3.04 (1.22,5.42)	0.55 (0.23,0.97)	8.7 (3.31,15.14)	0.48 (0.19,0.83)	-0.58 (-0.73,-0.44)
	Female	46.21 (17.87,83)	11.89 (4.59,21.41)	102.72 (37.96,181.08)	9.41 (3.5,16.57)	-0.88 (-1.04,-0.72)	1.8 (0.71,3.27)	0.55 (0.22,1)	4.58 (1.7,7.92)	0.44 (0.16,0.76)	-1.03 (-1.17,-0.88)
	Male	32.54 (12.26,61.3)	10.52 (4.07,18.76)	86.37 (31.78,156.94)	9.94 (3.68,17.93)	-0.14 (-0.32,0.04)	1.24 (0.46,2.29)	0.58 (0.22,1.04)	4.12 (1.56,7.52)	0.57 (0.22,1.04)	0 (-0.19,0.19)

DALYs: Disability-adjusted life years; UI: Uncertainty interval; SDI: Socio-Demographic Index; EAPC: Estimated annual percentage change; ASR: Age-standardized rate; no.: number

(95% CI: 0.3–0.49), indicating that the growth rate for male deaths was greater than that for females, although the overall trend remained relatively stable.

In high–middle-SDI regions, deaths increased by 168.31% (females: 9,450, 95% UI: 3,594–16,351; males: 6,600, 95% UI: 2,544–11,614), and DALYs increased by 122.06% (95% UI: 62.86–280.58). The growth rate for males was slightly greater than that for females. The EAPC of deaths in high–middle-SDI regions was 0.38 (95% CI: 0.26–0.50), with an EAPC of 0.61 (95% CI: 0.49–0.73) for females and − 0.08 (95% CI: -0.22– -0.05) for males (Table 1).

Burden of CKD attributable to physical inactivity in different continents

Africa had the greatest increase, with deaths increasing by 146.71% and DALYs increasing by 147.68%. The growth rate for females was significantly greater than that for males, with female deaths increasing by 174.36% compared with 114.67% for males. In 2021, the number of female deaths was 2,140 (95% UI: 760–3,940), whereas the number of male deaths was 1,610 (95% UI: 580–2,930). The EAPC of deaths in Africa was 0.11 (95% CI: 0.05–0.18), with an EAPC of 0.41 (95% CI: 0.36–0.46) for females and − 0.26 (95% CI: -0.35–0.17) for males (Table 1).

Europe had the smallest increase in burden, with deaths increasing by 143.83% and DALYs increasing by 75.56%. Males presented a greater growth rate for both indicators than females did. In 2021, the number of female deaths was 3,710 (95% UI: 1,450–6,850), whereas the number of male deaths was 2,020 (95% UI: 760–3,700). The EAPC of deaths in Europe was 1.02 (95% CI: 0.87–1.16), with an EAPC of 1.39 (95% CI: 1.24–1.55) for females and 0.17 (95% CI: 0.02–0.31) for males.

In Asia, deaths increased by 193.54% (females: 26,430, 95% UI: 9,928–45,833; males: 22,120, 95% UI: 8,253–39,800), and DALYs increased by 156.57% (95% UI: 185.82–859.16). The growth rate for males was slightly greater than that for females. The EAPC of deaths in Asia was − 0.11 (95% CI: -0.18–0.05), with an EAPC of -0.34 (95% CI: -0.40–0.27) for females and 0.20 (95% CI: 0.12–0.29) for males.

In the Americas, deaths increased by 281.92%, and DALYs increased by 236.06%, with males consistently having a higher growth rate than females did. The EAPC of deaths in the Americas was 1.70 (95% CI: 1.46–1.93), with an EAPC of 1.76 (95% CI: 1.43–2.09) for females and 1.53 (95% CI: 1.38–1.67) for males (Table 1).

Burden of CKD attributable to physical inactivity in China

In China, the number of deaths increased by 140.14% (females: 102,720, 95% UI: 37,961–181,080; males: 86,370, 95% UI: 31,780–156,940), and DALYs increased by 140.14% (95% UI: 3.68–17.93). The growth rate for males was slightly greater than that for females. The EAPC of deaths in China was − 0.14 (95% CI: -0.32–0.04).

Globally, the burden of CKD attributable to physical inactivity has increased significantly, especially in low-SDI regions and developing continents, highlighting the urgency of effective preventive measures and interventions worldwide. Furthermore, there are significant sex differences in growth rates globally. Overall, although the growth rate for males was slightly greater than that for females, in many cases, the number of deaths and DALYs for females remained greater than those for males, underscoring the importance of sex differences in the global burden of CKD (Table 1).

From 1990 to 2021, the DALY and mortality rates of chronic kidney disease (CKD) caused by low physical activity steadily increased, with the trend becoming more pronounced with age. In the 25–54 years age group, the burden remains low but gradually increases, indicating potential future risks (Fig. 2). From 55 years of age onwards, the rates increase sharply, particularly among the 65 + age group, with the 85 + group experiencing the highest burden (Fig. 2). Countries with lower SDI levels face greater burdens across all age groups, whereas high-SDI countries benefit from better healthcare and have lower rates. Men have slightly higher rates than women do, although the difference is small. In China, the trend mirrors global patterns, with the burden among older adults continuing to grow (Table 1).

Decomposition analysis

This study revealed that the burden of chronic kidney disease (CKD) caused by physical inactivity increased significantly between 1990 and 2021, with DALYs (disability-adjusted life years) increasing across various countries and regions. For example, DALYs increased in Africa (from 39,800 to 98,600), Asia (from 89,200 to 485,600), and the Americas (from 66,000 to 221,900). According to the sociodemographic index (SDI) groups, DALYs rose in low-SDI countries (from 60,000 to 158,000) and high-SDI countries (from 81,300 to 212,200). These trends highlight that physical inactivity is a global issue, with low-income regions bearing the highest burden, whereas high-income countries are increasingly affected by aging populations (Table 2).

Gender analysis revealed that women carry a greater CKD burden than men do, particularly in high-income countries, which is driven by aging. For example, DALYs in 2021 were 56,800 for women and 41,700 for men in Africa and 102,700 for women and 86,400 for men in China. However, the increase in mortality was more pronounced among men, particularly in Asia and the Americas, suggesting that male populations face significant challenges in CKD management and prevention. Elderly

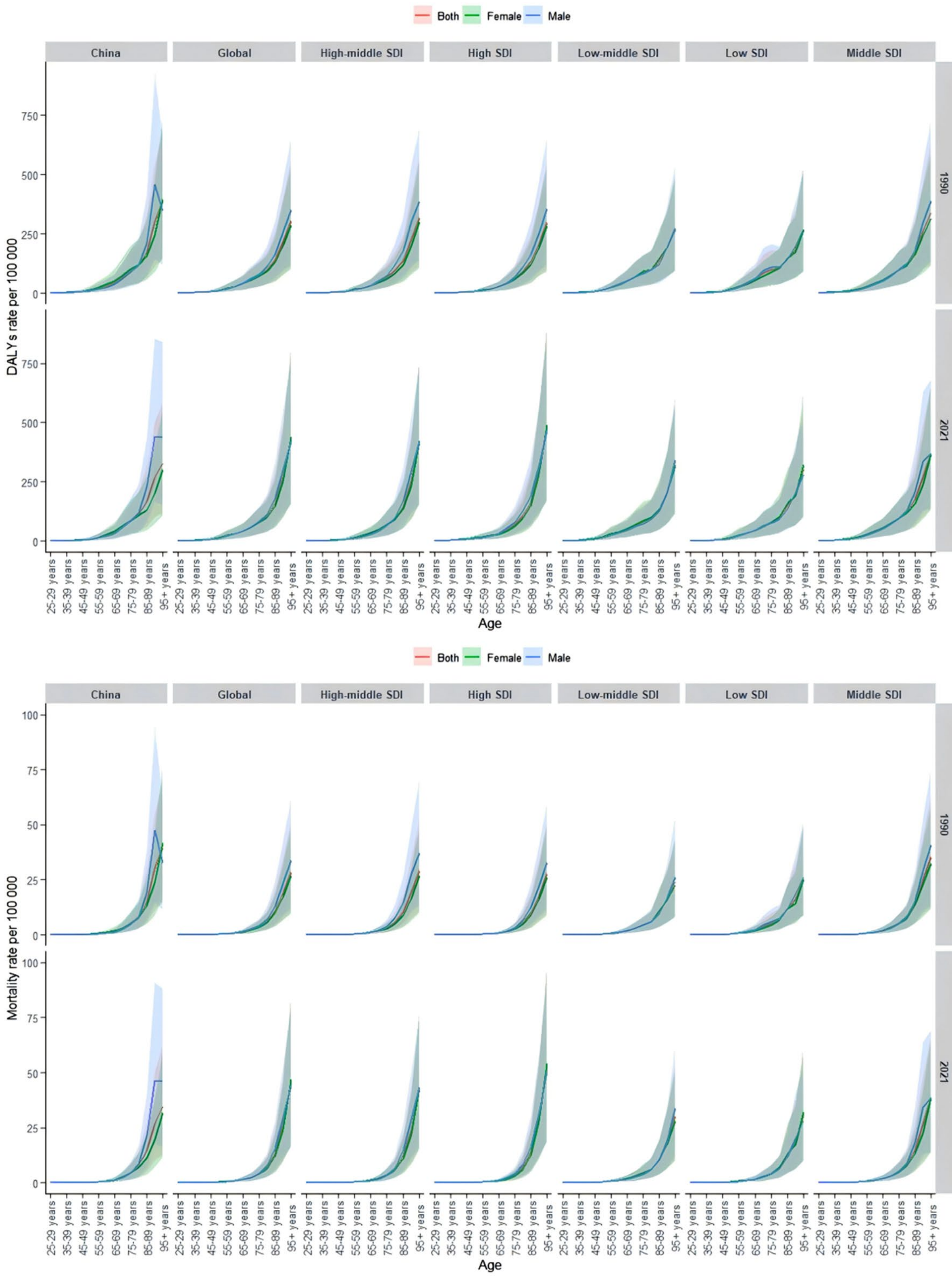

Fig. 2 Trends in ASMR and ASDR for CKD Attributable to LPA Across Age Groups in Different Regions (China, Global, and SDI Levels) in 1990 and 2021

individuals experienced a significant increase in both DALYs and mortality. For example, DALYs among the 75–84 age group rose in Asia (from 38,100 to 105,200) and Europe (from 19,800 to 27,400). Similarly, elderly mortality has increased, with deaths in the 75–84 age group increasing in Europe (from 8,400 to 21,300) and the Americas (from 2,900 to 11,400). These findings emphasize that the impact of physical inactivity is most

Table 2 Decomposition analysis of Disability-Adjusted life years (DALYs) and deaths per 100,000 for chronic kidney disease attributable to low physical activity by region and SDI level, 1990 and 2021

Measure	Variable	Africa		America		Asia		China		Europe		Global		High-middle SDI		High SDI		Low-middle SDI		Low SDI		Middle SDI	
		1990	2021	1990	2021	1990	2021	1990	2021	1990	2021	1990	2021	1990	2021	1990	2021	1990	2021	1990	2021	1990	2021
DALYs	**Total**	0.398	0.986	0.66	2.219	1.892	4.856	0.788	1.891	0.593	1.041	3.558	9.131	0.723	1.605	0.813	2.122	0.6	1.58	0.249	0.501	1.17	3.313
DALYs	**Sex**																						
DALYs	Female	0.207 (51.971)	0.568 (57.661)	0.354 (53.563)	1.181 (53.247)	1.031 (54.455)	2.643 (54.436)	0.462 (58.683)	1.027 (54.323)	0.355 (59.777)	0.646 (62.037)	1.953 (54.877)	5.054 (55.352)	0.418 (57.836)	0.945 (58.878)	0.473 (58.176)	1.162 (54.763)	0.304 (50.589)	0.888 (56.217)	0.12 (48.329)	0.271 (54.077)	0.636 (54.352)	1.783 (53.798)
DALYs	Male	0.191 (48.029)	0.417 (42.339)	0.307 (46.437)	1.037 (46.753)	0.862 (45.545)	2.212 (45.564)	0.325 (41.317)	0.864 (45.677)	0.239 (40.223)	0.395 (37.963)	1.606 (45.123)	4.077 (44.648)	0.305 (42.164)	0.66 (41.122)	0.34 (41.824)	0.96 (45.237)	0.296 (49.411)	0.692 (43.783)	0.128 (51.671)	0.23 (45.923)	0.534 (45.648)	1.531 (46.202)
DALYs	**Age**																						
DALYs	25–44	0.037 (9.327)	0.125 (12.649)	0.056 (8.408)	0.134 (6.035)	0.138 (7.288)	0.281 (5.782)	0.055 (6.936)	0.045 (2.359)	0.023 (3.881)	0.025 (2.366)	0.255 (7.156)	0.565 (6.192)	0.038 (5.289)	0.051 (3.172)	0.038 (4.669)	0.089 (4.18)	0.048 (7.947)	0.15 (9.512)	0.019 (7.788)	0.056 (11.105)	0.111 (9.499)	0.219 (6.616)
DALYs	45–64	0.153 (38.528)	0.409 (41.451)	0.197 (29.791)	0.715 (32.232)	0.7 (37.015)	1.531 (31.536)	0.274 (34.839)	0.469 (24.811)	0.129 (21.707)	0.167 (16.006)	1.184 (33.277)	2.829 (30.987)	0.218 (30.147)	0.402 (25.049)	0.178 (21.93)	0.425 (20.047)	0.239 (39.909)	0.629 (39.835)	0.1 (40.124)	0.199 (39.782)	0.447 (38.241)	1.17 (35.312)
DALYs	65–74	0.117 (29.493)	0.235 (23.817)	0.165 (24.923)	0.549 (24.732)	0.553 (29.216)	1.344 (27.689)	0.247 (31.373)	0.611 (32.301)	0.135 (22.798)	0.194 (18.661)	0.974 (27.371)	2.33 (25.515)	0.196 (27.113)	0.428 (26.661)	0.194 (23.872)	0.437 (20.605)	0.173 (28.882)	0.416 (26.304)	0.08 (32.113)	0.133 (26.616)	0.33 (28.184)	0.913 (27.563)
DALYs	75–84	0.069 (17.418)	0.155 (15.752)	0.158 (23.944)	0.477 (21.506)	0.381 (20.139)	1.052 (21.672)	0.171 (21.773)	0.509 (26.895)	0.198 (33.431)	0.274 (26.285)	0.81 (22.764)	1.966 (21.533)	0.193 (26.683)	0.399 (24.871)	0.257 (31.586)	0.543 (25.6)	0.106 (17.695)	0.271 (17.153)	0.04 (16.238)	0.084 (16.668)	0.213 (18.193)	0.667 (20.139)
DALYs	85–94	0.019 (4.885)	0.058 (5.851)	0.074 (11.247)	0.279 (12.571)	0.111 (5.888)	0.555 (11.438)	0.038 (4.88)	0.237 (12.521)	0.098 (16.541)	0.309 (29.625)	0.305 (8.561)	1.205 (13.194)	0.072 (9.934)	0.279 (17.357)	0.129 (15.904)	0.494 (23.288)	0.031 (5.115)	0.099 (6.257)	0.009 (3.478)	0.027 (5.364)	0.064 (5.456)	0.305 (9.208)
DALYs	95+	0.001 (0.349)	0.005 (0.481)	0.011 (1.687)	0.065 (2.924)	0.009 (0.454)	0.091 (1.883)	0.002 (0.199)	0.021 (1.112)	0.01 (1.641)	0.073 (7.058)	0.031 (0.871)	0.235 (2.579)	0.006 (0.834)	0.046 (2.891)	0.017 (2.038)	0.133 (6.28)	0.003 (0.451)	0.015 (0.938)	0.001 (0.259)	0.002 (0.465)	0.005 (0.427)	0.038 (1.161)
Deaths	**Total**	0.015	0.038	0.027	0.104	0.071	0.209	0.03	0.087	0.023	0.057	0.138	0.409	0.028	0.076	0.035	0.116	0.022	0.059	0.009	0.019	0.043	0.138
Deaths	**Sex**																						
Deaths	Female	0.008 (50.997)	0.021 (57.176)	0.015 (54.661)	0.056 (54.093)	0.039 (55.239)	0.114 (54.412)	0.018 (59.094)	0.046 (52.673)	0.014 (60.03)	0.037 (64.731)	0.076 (55.444)	0.229 (56.024)	0.016 (57.33)	0.045 (59.604)	0.021 (60.54)	0.067 (57.379)	0.011 (50.168)	0.033 (55.498)	0.004 (46.235)	0.01 (53.125)	0.024 (54.736)	0.074 (53.523)
Deaths	Male	0.007 (49.003)	0.016 (42.824)	0.012 (45.339)	0.048 (45.907)	0.032 (44.761)	0.095 (45.588)	0.012 (40.906)	0.041 (47.327)	0.009 (39.97)	0.02 (35.269)	0.061 (44.556)	0.18 (43.976)	0.012 (42.67)	0.031 (40.396)	0.014 (39.46)	0.05 (42.621)	0.011 (49.832)	0.026 (44.502)	0.005 (53.765)	0.009 (46.875)	0.02 (45.264)	0.064 (46.477)
Deaths	**Age**																						
Deaths	25–44	0.001 (3.383)	0.002 (4.892)	0.001 (2.603)	0.002 (1.8)	0.002 (2.696)	0.004 (1.828)	0.001 (2.877)	0.001 (0.76)	0 (0.807)	0 (0.327)	0.003 (2.431)	0.008 (1.89)	0.001 (1.766)	0.001 (0.851)	0 (1.09)	0.001 (0.978)	0.001 (2.815)	0.002 (3.525)	0 (2.974)	0.001 (4.292)	0.002 (3.63)	0.003 (2.205)
Deaths	45–64	0.004 (25.789)	0.01 (27.713)	0.005 (16.829)	0.018 (17.403)	0.017 (23.854)	0.036 (17.278)	0.007 (22.144)	0.01 (11.88)	0.002 (9.205)	0.003 (5.018)	0.028 (20.17)	0.068 (16.533)	0.005 (16.832)	0.009 (11.497)	0.003 (9.612)	0.009 (7.845)	0.006 (27.619)	0.016 (26.904)	0.003 (28.438)	0.005 (26.964)	0.011 (25.315)	0.029 (20.769)
Deaths	65–74	0.005 (30.997)	0.01 (25.551)	0.006 (22.289)	0.022 (21.173)	0.021 (28.937)	0.05 (23.809)	0.009 (30.585)	0.022 (25.682)	0.004 (16.165)	0.006 (10.313)	0.035 (25.661)	0.088 (21.397)	0.007 (23.701)	0.015 (19.78)	0.006 (17.638)	0.015 (13.264)	0.007 (30.657)	0.016 (27.659)	0.003 (35.009)	0.005 (28.552)	0.013 (28.88)	0.035 (25.488)
Deaths	75–84	0.004 (27.542)	0.01 (26.166)	0.009 (32.472)	0.029 (28.149)	0.021 (29.927)	0.06 (28.547)	0.01 (32.444)	0.03 (34.056)	0.009 (40.024)	0.014 (25.147)	0.044 (31.888)	0.114 (27.764)	0.01 (35.818)	0.023 (29.601)	0.013 (38.34)	0.031 (26.697)	0.006 (26.72)	0.015 (25.934)	0.002 (25.164)	0.005 (26.398)	0.012 (28.169)	0.04 (28.619)
Deaths	85–94	0.002 (11.352)	0.005 (14.334)	0.006 (21.956)	0.026 (24.779)	0.01 (13.384)	0.05 (23.794)	0.003 (11.419)	0.022 (25.085)	0.007 (30.168)	0.026 (45.905)	0.024 (17.736)	0.108 (26.283)	0.006 (19.94)	0.024 (32.028)	0.01 (28.912)	0.045 (38.589)	0.002 (11.065)	0.008 (13.661)	0.001 (7.748)	0.002 (12.547)	0.006 (12.815)	0.028 (20.018)
Deaths	95+	0 (0.937)	0.001 (1.344)	0.001 (3.852)	0.007 (6.696)	0.001 (1.203)	0.01 (4.745)	0 (0.531)	0.002 (2.536)	0.001 (3.631)	0.008 (13.291)	0.003 (2.113)	0.025 (6.133)	0.001 (1.944)	0.005 (6.243)	0.002 (4.407)	0.015 (12.627)	0 (1.124)	0.001 (2.317)	0 (0.667)	0 (1.247)	0.001 (1.191)	0.004 (2.9)

SDI Socio-Demographic Index

severe among elderly individuals, greatly increasing mortality risks (Fig. 3 and Table 3).

According to Table S2, population growth is the primary driver of increasing global DALYs and mortality, with low-SDI countries and Africa being the most affected countries. While some improvements have been observed in China and parts of high-SDI countries, the overall burden continues to grow. To address the increasing disease burden and mortality effectively, countries must prioritize physical activity promotion, early screening, and chronic disease management to mitigate CKD progression and improve population health outcomes.

ARIMA model for CKD burden caused by LPA

This study used the ARIMA model to predict mortality rates and the number of mortalities among patients with chronic kidney disease (CKD) due to low physical activity (LPA). The auto.arima function from the forecast package was used for model selection, resulting in an ARIMA(0,2,1) model for both male and overall populations and an ARIMA(1,2,0) model for females. For the LPA-related CKD mortality rates, the AIC values were −273.34 (males), -252.27 (females), and −266.08 (overall). For the number of mortalities, the AIC values were 354.35 (males), 375.63 (females), and 402.96 (overall), with corresponding BIC values of 357.15, 378.43, and 405.76 and AICC values of 354.79, 376.07, and 403.40, respectively. All the models showed high consistency between the observed and fitted values, with a correlation coefficient of 0.99 ($P<0.0001$), indicating good model fit. The residuals ranged from −0.01 to 0.01 and followed a normal distribution on the basis of the Q–Q,

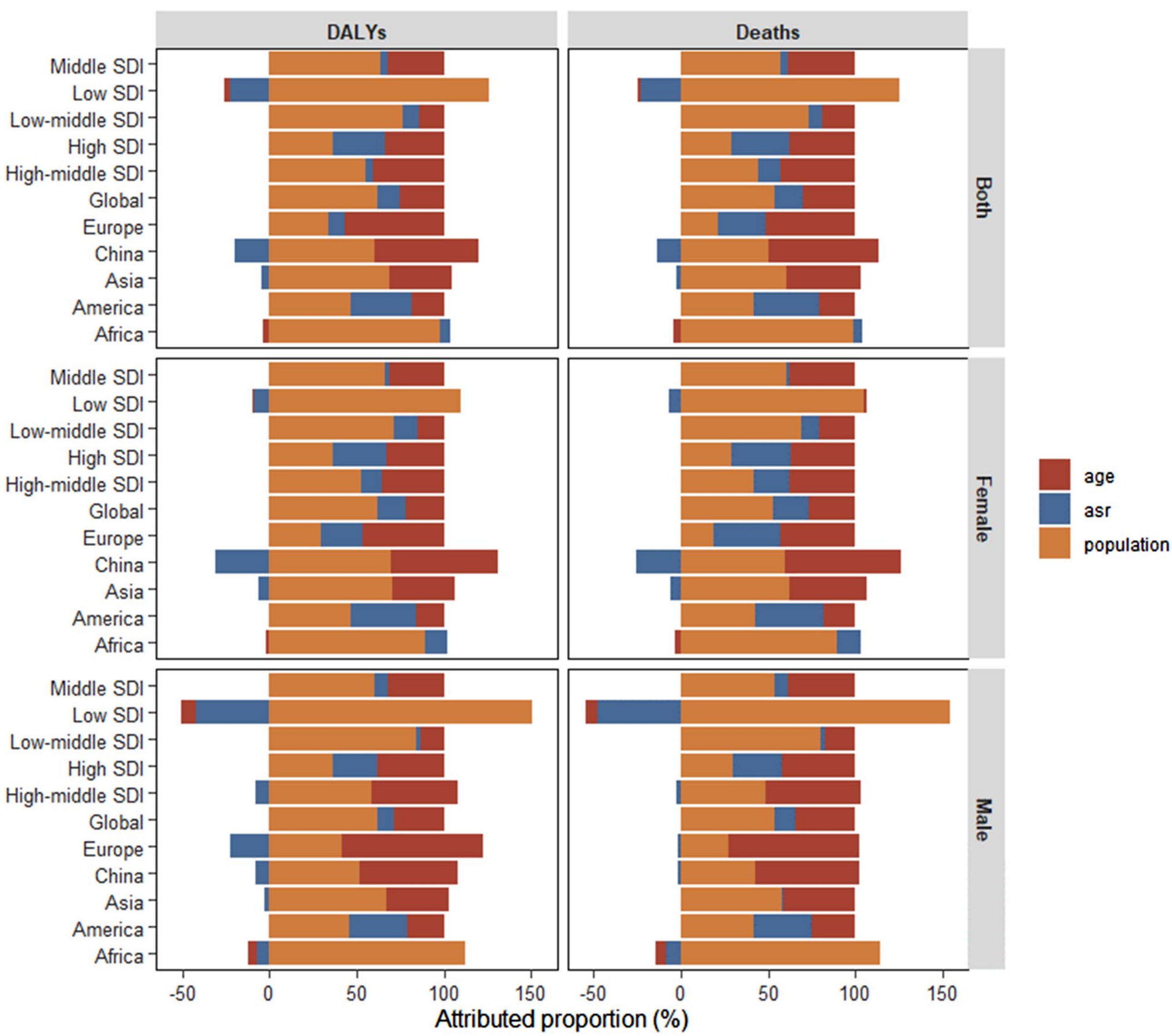

Fig. 3 Decomposition analysis of DALYs and deaths attributable to CKD Caused by low physical activity by region, sex, and SDI levels

Table 3 Decomposition analysis of chronic kidney disease (CKD) attributable to low physical activity by population growth, Age-Standardized rates (ASR), and regional contributions

Variable	Age	Population	Asr	Total
DALYs, Both				
Africa	-0.02(-3.377)	0.576(98.007)	0.032(5.37)	0.588
America	0.283(18.165)	0.723(46.369)	0.553(35.467)	1.558
Asia	1.058(35.691)	2.041(68.877)	-0.135(-4.568)	2.963
China	0.653(59.161)	0.667(60.434)	-0.216(-19.595)	1.103
Europe	0.256(57.17)	0.152(33.928)	0.04(8.902)	0.448
Global	1.386(24.872)	3.449(61.888)	0.738(13.24)	5.572
High-middle SDI	0.359(40.733)	0.485(54.929)	0.038(4.338)	0.882
High SDI	0.445(34.002)	0.481(36.713)	0.383(29.285)	1.309
Low-middle SDI	0.14(14.251)	0.747(76.242)	0.093(9.507)	0.98
Low SDI	-0.01(-4.119)	0.319(126.109)	-0.056(-21.989)	0.253
Middle SDI	0.683(31.853)	1.363(63.573)	0.098(4.574)	2.144
DALYs, **Female**				
Africa	-0.008(-2.129)	0.323(89.408)	0.046(12.721)	0.361
America	0.134(16.169)	0.386(46.668)	0.308(37.162)	0.828
Asia	0.575(35.68)	1.139(70.609)	-0.101(-6.289)	1.613
China	0.347(61.43)	0.392(69.375)	-0.174(-30.805)	0.565
Europe	0.136(46.661)	0.086(29.493)	0.07(23.846)	0.291
Global	0.688(22.171)	1.916(61.784)	0.498(16.045)	3.101
High-middle SDI	0.187(35.551)	0.276(52.466)	0.063(11.983)	0.527
High SDI	0.224(32.535)	0.252(36.636)	0.212(30.829)	0.689
Low-middle SDI	0.089(15.242)	0.415(70.978)	0.081(13.78)	0.585
Low SDI	-0.001(-0.89)	0.165(109.431)	-0.013(-8.54)	0.151
Middle SDI	0.359(31.328)	0.762(66.421)	0.026(2.251)	1.147
DALYs, **Male**				
Africa	-0.012(-5.275)	0.253(112.073)	-0.015(-6.799)	0.226
America	0.154(21.112)	0.336(46.047)	0.24(32.841)	0.731
Asia	0.479(35.474)	0.907(67.157)	-0.036(-2.631)	1.351
China	0.304(56.469)	0.279(51.814)	-0.045(-8.283)	0.538
Europe	0.128(81.505)	0.065(41.312)	-0.036(-22.817)	0.157
Global	0.708(28.665)	1.536(62.165)	0.227(9.17)	2.471
High-middle SDI	0.177(49.83)	0.207(58.365)	-0.029(-8.195)	0.355
High SDI	0.235(37.958)	0.225(36.315)	0.16(25.727)	0.62
Low-middle SDI	0.051(12.912)	0.334(84.399)	0.011(2.69)	0.395
Low SDI	-0.009(-9.028)	0.153(150.706)	-0.042(-41.678)	0.102
Middle SDI	0.322(32.267)	0.605(60.69)	0.07(7.042)	0.997
Deaths, **Both**				
Africa	-0.001(-4.044)	0.022(98.706)	0.001(5.338)	0.022
America	0.016(20.972)	0.032(41.947)	0.028(37.081)	0.076
Asia	0.059(42.923)	0.083(60.071)	-0.004(-2.993)	0.138
China	0.036(62.97)	0.029(50.548)	-0.008(-13.518)	0.057
Europe	0.017(51.293)	0.007(21.454)	0.009(27.254)	0.034
Global	0.081(29.777)	0.145(53.304)	0.046(16.918)	0.271
High-middle SDI	0.021(43.329)	0.021(44.225)	0.006(12.446)	0.048
High SDI	0.031(37.874)	0.024(29.223)	0.027(32.902)	0.082
Low-middle SDI	0.007(19.458)	0.028(73.55)	0.003(6.993)	0.037
Low SDI	0(-1.547)	0.012(124.93)	-0.002(-23.383)	0.01
Middle SDI	0.036(38.315)	0.054(57.141)	0.004(4.544)	0.095
Deaths, **Female**				
Africa	0(-3.152)	0.012(89.024)	0.002(14.128)	0.014
America	0.008(18.598)	0.017(42.339)	0.016(39.063)	0.041
Asia	0.033(43.915)	0.047(62.47)	-0.005(-6.385)	0.075

Table 3 (continued)

Variable	Age	Population	Asr	Total
China	0.019(66.387)	0.017(59.436)	-0.007(-25.823)	0.028
Europe	0.01(42.742)	0.004(18.414)	0.009(38.844)	0.023
Global	0.041(26.889)	0.081(53.162)	0.031(19.948)	0.153
High-middle SDI	0.011(37.849)	0.012(41.57)	0.006(20.582)	0.029
High SDI	0.017(36.587)	0.013(28.543)	0.016(34.869)	0.046
Low-middle SDI	0.005(20.967)	0.015(69.012)	0.002(10.021)	0.022
Low SDI	0(1.75)	0.006(104.895)	0(-6.645)	0.006
Middle SDI	0.019(38.057)	0.03(60.285)	0.001(1.658)	0.05
Deaths, Male				
Africa	0(-5.594)	0.01(114.355)	-0.001(-8.761)	0.009
America	0.009(24.726)	0.015(41.521)	0.012(33.753)	0.035
Asia	0.026(41.464)	0.037(57.572)	0.001(0.965)	0.064
China	0.017(59.714)	0.012(42.481)	-0.001(-2.195)	0.029
Europe	0.008(74.571)	0.003(27.235)	0(-1.806)	0.011
Global	0.041(34.233)	0.064(53.653)	0.014(12.114)	0.119
High-middle SDI	0.01(54.39)	0.009(48.287)	-0.001(-2.677)	0.019
High SDI	0.015(42.273)	0.011(29.51)	0.01(28.217)	0.036
Low-middle SDI	0.003(17.279)	0.012(80.26)	0(2.462)	0.015
Low SDI	0(-6.823)	0.006(154.406)	-0.002(-47.583)	0.004
Middle SDI	0.017(38.325)	0.024(53.945)	0.003(7.731)	0.045

DALYs: Disability-adjusted life-years

ACF, and PACF plots. The Ljung-Box test confirmed that the residuals were white noise for all the models (male: $Q=4.19$, $P=0.52$; female: $Q=9.21$, $P=0.10$; overall: $Q=6.71$, $P=0.24$), with similar results for predicting the number of mortalities (male: $Q=4.39$, $P=0.50$; female: $Q=8.53$, $P=0.13$; overall: $Q=6.29$, $P=0.28$), indicating good model fit and residual randomness (Supplementary Material, SFig. 1 and SFig. 2).

The projections indicate that over the next decade, the global trend of low physical activity (LPA) is expected to lead to a continued rise in both mortality rates and the number of deaths among CKD patients, including males, females, and the overall population (Fig. 4). Specifically, the mortality rate per 100,000 people for males is expected to increase from 0.46% in 2022 to 0.55% in 2031, whereas for females, it is projected to rise from 0.60% in 2022 to 0.71% in 2031, and for the overall population, it is expected to increase from 0.53 to 0.63% during the same period. In terms of the number of deaths, the number of males is projected to increase from 17,994.22 in 2021 to 23,480.96 in 2031, and the number of females is projected to increase from 22,924.25 to 30,132.89. Overall, the number of deaths among males is expected to increase by 5,486.74, whereas for females, the increase is projected to be 7,208.64, indicating a more pronounced increase in females. These projections provide valuable insights into future mortality trends among CKD patients under conditions of low physical activity (Supplementary Material, STable. 1–4).

Frontier analysis of CKD burden caused by LPA

The countries or regions with the largest effective differences from the frontier include American Samoa, Micronesia, the Marshall Islands, Saudi Arabia, and Niue, indicating a significant gap between their current CKD burden and the optimal level for their SDI. These regions require further public health interventions and lifestyle changes. In contrast, Tajikistan, Ukraine, Belarus, Canada, and Eastern Europe have smaller effective differences, suggesting that their CKD burdens are closer to the optimal level, although minor improvements are still possible (Fig. 5).

The black solid line represents the frontier, with each dot marking a country or region. The blue dots indicate progress toward the frontier, whereas the red dots represent a worsening trend. This analysis underscores the need for targeted interventions tailored to each region's development level to reduce the impact of low physical activity on CKD (Fig. 5).

Discussion

This study highlights the significant impact of low physical activity on the global burden of chronic kidney disease (CKD) and examines differences according to sex, age, and region. These findings are related to changes in disease patterns and reflect the influence of demographic structure, economic development, and healthcare conditions.

The increasing global CKD burden has several key trends. First, the increase in deaths and

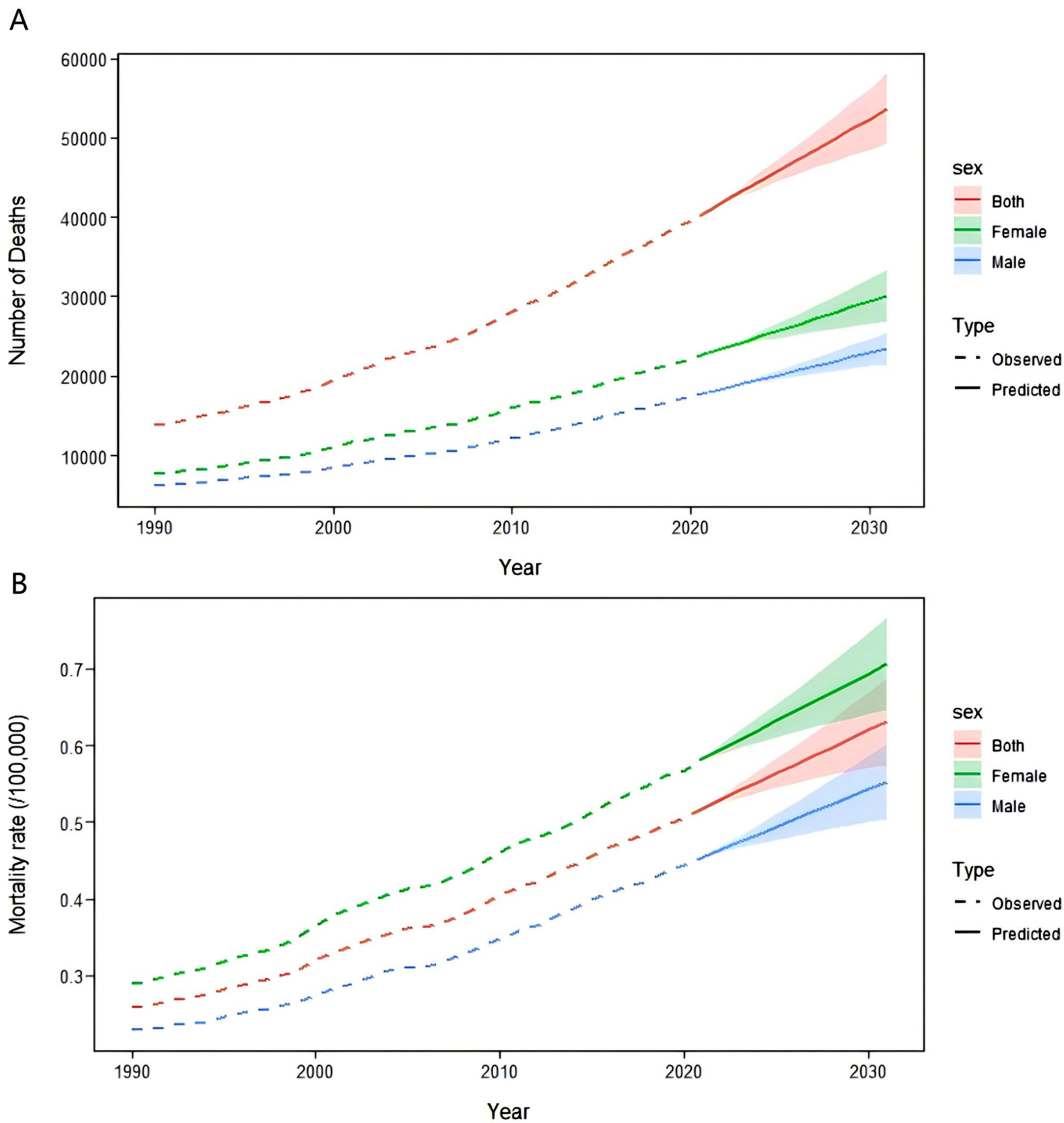

Fig. 4 Predicted Trends in CKD Mortality Attributable to Low Physical Activity by Sex: Number of Deaths (**A**) and Mortality Rates (**B**) from 1990 to 2031; Solid lines and shaded regions represent the predicted trend and its 95% confidence interval (CI). Dashed lines indicate the observed data

disability-adjusted life years (DALYs) (197.21% for deaths and 156.60% for DALYs) is due primarily to population growth and aging. Studies have shown that population aging significantly contributes to noncommunicable diseases (NCDs) [21]. Similarly, this study revealed a significant increase in CKD mortality and DALYs among elderly individuals, indicating the substantial impact of population aging on CKD due to low physical activity [22].

Although deaths and DALYs are increasing in absolute terms, the estimated annual percentage change (EAPC) has decreased in some regions, particularly in low-SDI areas. This may be linked to the epidemiological shift from infectious diseases to NCDs. In low-income countries, healthcare resources have gradually shifted from

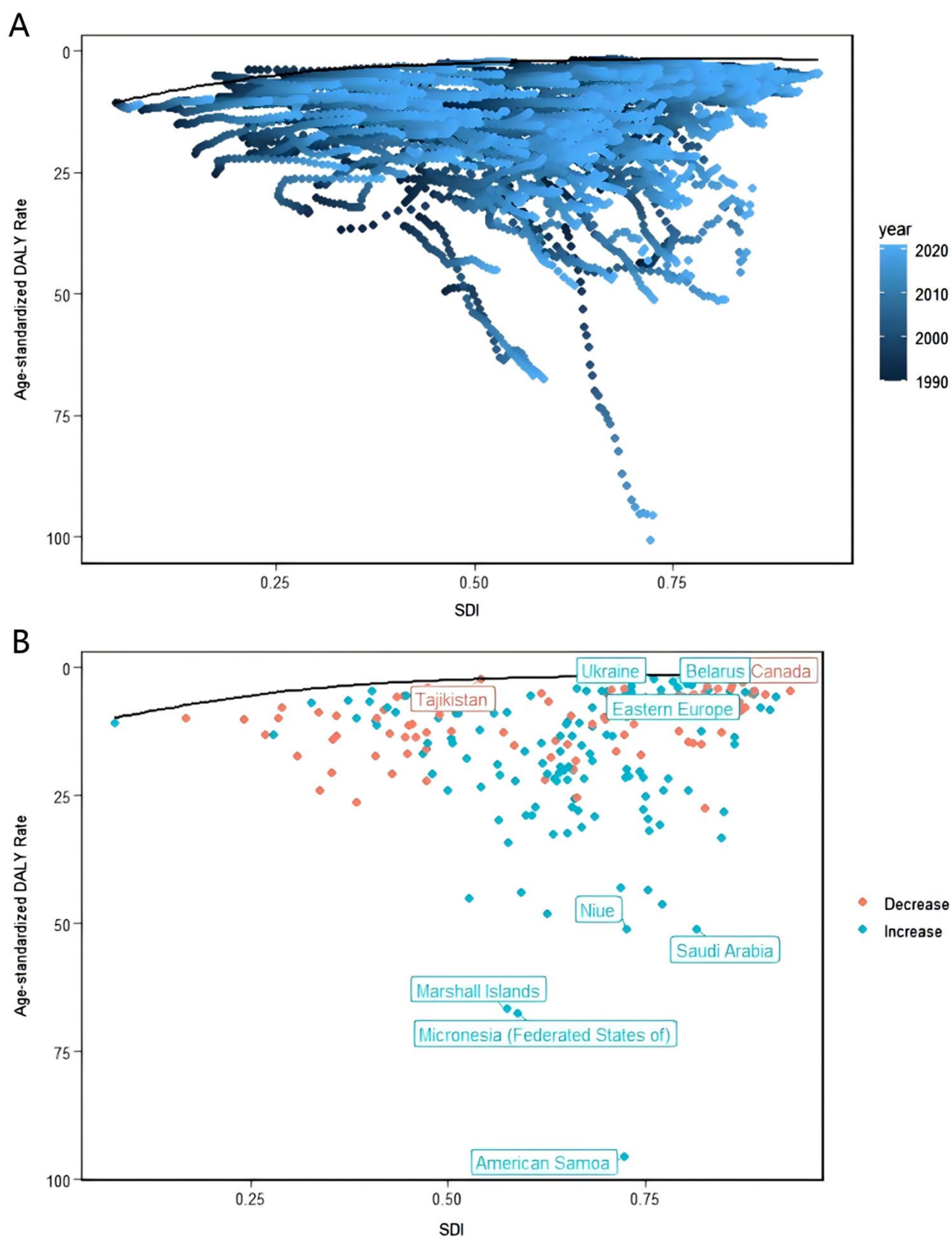

Fig. 5 (**A**) Frontier analysis based on SDI and gout DALYs rate from 1990 to 2021. (**B**) Frontier analysis based on SDI and gout DALYs rate in 2021. DALYs, disability-adjusted life years; SDI, sociodemographic index

infectious disease control to managing NCDs, which may have slowed the rapid increase in CKD burden [23]. However, these countries still face significant health challenges, with limited public health resources and low health awareness, slowing reductions in mortality and disease burden.

In high-income countries and high-SDI regions, the increase in CKD burden (e.g., a 234.48% increase in deaths and a 161.05% increase in DALYs) is closely linked to unhealthy lifestyles and chronic disease effects [24]. Despite advances in medical technology and chronic disease management, lifestyle factors such as physical inactivity and unhealthy diets continue to drive CKD and other chronic diseases. Additionally, pronounced aging in high-income regions further exacerbates the CKD burden [25].

Physical activity plays a key role in preventing and managing CKD. Studies have shown that increasing physical exercise by 10 MET hours per week can reduce CKD risk by approximately 2%, indicating a clear dose–response relationship between physical activity and CKD—more activity means a lower disease risk [26, 27]. Exercise also helps manage comorbidities such as hypertension and diabetes, slowing kidney decline and improving quality of life [28, 29]. Conversely, prolonged inactivity increases the risk of hospitalization and death, accelerating CKD progression [30].

It is worth noting that although this study focuses on low physical activity as an individual risk factor, it often coexists and interacts with other modifiable factors such as poor diet, obesity, hypertension, diabetes, and cardiovascular disease [31]. These factors share common biological pathways, including inflammation, oxidative stress, and metabolic dysregulation, that accelerate the onset and progression of CKD. Recognizing these interactions is important for informing more comprehensive prevention strategies in future research and practice.

Furthermore, the prevalence and prognosis of chronic kidney disease are closely associated with socioeconomic status, with marked disparities observed across different populations and regions [32]. Income inequality may lead to an uneven distribution of health resources, limiting low-income groups' access to effective medical interventions and thereby exacerbating the CKD burden; similarly, lower education levels can result in insufficient health literacy and reduced physical activity, increasing CKD risk [33]. In addition, limited accessibility to healthcare services may delay diagnosis and treatment, making patients more likely to progress to advanced CKD and further increasing the overall disease burden [34].

Policymakers should promote regular physical activity in schools, communities, and workplaces to prevent CKD. Finland's North Karelia Project is a successful example, reducing cardiovascular mortality by 84% (1972–2014) through lifestyle and environmental changes, offering a sustainable model for chronic disease prevention.

Gender differences in CKD burden deserve attention, as the rate of increase among women is higher than that among men, with an EAPC of 0.71. This suggests that despite a longer life expectancy, health management in older women remains insufficient [35]. The rising trend may be attributed to both biological and social factors. Biologically, the decline in estrogen levels after menopause may impair renal function and increase CKD risk [36], while sex-specific characteristics in immune and inflammatory responses may also play a role [37, 38]. Socially, limited access to healthcare and health education, partly due to economic constraints and religious beliefs, can delay early diagnosis and treatment, especially in low-SDI regions [39, 40]. In addition, chronic stress from managing multiple social roles may negatively affect women's [41]. In contrast, in some regions such as Asia and the Americas, men have experienced a greater increase in CKD mortality, possibly related to higher smoking rates, poor diet, and lower health awareness among middle-aged and older males [42].

ARIMA model projections indicate that the CKD burden will continue to rise over the next decade, especially among women and elderly individuals. Despite progress in medical technology and chronic disease management, delayed changes in lifestyle factors will continue to increase the burden of CKD. Therefore, future strategies should emphasize promoting healthy lifestyles and early interventions [43], particularly for high-risk groups such as elderly individuals and those with chronic conditions [44]. To enhance the effectiveness of health interventions, region-specific strategies should be developed based on SDI levels. In low-SDI regions, priorities include improving health literacy, expanding access to low-cost physical activity, and providing health education through community or religious organizations [45]. Middle-SDI regions may benefit from public campaigns and community-based programs to raise awareness and participation [46]. In high-SDI regions, personalized exercise prescriptions and strategies to reduce sedentary behavior are recommended [47]. Successful models include WHO's CHW programs, school-based interventions in Latin America and Southeast Asia [48], and national media campaigns such as "Verb," "Push Play," and "ParticipACTION" [46].

Overall, this study underscores the significant increase in the global CKD burden due to low physical activity, with variations across countries, regions, and socioeconomic levels. Countries should formulate appropriate public health strategies based on their social and economic conditions to encourage physical activity and reduce CKD risk. Future research should also explore the barriers faced by high-risk groups to facilitate targeted interventions, while further efforts are needed to integrate objective measures of physical activity, such as wearable device data, to reduce self-report bias. In addition, longitudinal and interventional studies are needed to better establish the causal relationship between low physical activity and CKD. Further efforts should also focus on improving data completeness in low-income regions and developing more comprehensive socioeconomic indicators beyond SDI to capture the full context of CKD burden.

Limitations and strengths

This study has some limitations. First, the assessment of low physical activity primarily relies on self-reported data, which might lead to measurement errors or recall bias. Second, the relative risks used in observational studies may not accurately reflect causal relationships and could be confounded. Additionally, data quality and availability vary across countries and regions, potentially influencing accuracy and comparability. Finally, the SDI may not encompass all socioeconomic factors that could affect CKD and physical activity, which might influence the findings.

While acknowledging the above limitations, this study offers several notable strengths. It draws on the GBD 2021 database, which provides standardized and comparable data across countries, regions, and time. This allowed us to assess the global and regional burden of CKD attributable to low physical activity over a 30-year period. Unlike previous studies with limited scope, our work offers a broader perspective. The inclusion of the Sociodemographic Index (SDI) enabled analysis of how socioeconomic development relates to disease burden, supporting stratified and inequality-focused evaluations. Additionally, we applied advanced methods—such as EAPC, decomposition analysis, ARIMA model, and frontier analysis—to deepen understanding and enhance policy relevance. These features extend existing knowledge and offer new insights into the global distribution of CKD burden.

Conclusion

This study, using GBD 2021 data, assessed the global burden of CKD attributable to low physical activity from 1990 to 2021. Despite some regional declines in mortality rates, global CKD-related deaths and DALYs have risen significantly, especially in low-SDI regions, among older adults, and in females. Projections indicate continued increases over the next decade, highlighting the urgency of early intervention. To address this burden, region-specific strategies should be implemented. Low-SDI regions should prioritize health literacy and accessible physical activity; middle-SDI areas may benefit from community-based programs; high-SDI countries should focus on personalized interventions and reducing sedentary behavior. Special attention is needed for women and the elderly, who face higher risks. These findings offer critical guidance for public health planning and underscore the need for future research on effective, context-specific interventions tailored to different SDI levels and vulnerable populations.

Abbreviations

ACF	Autocorrelation function
AIC	Akaike information criterion
ARIMA	Auto-Regressive Integrated Moving Average
ASDR	Age-standardized DALY rate
ASMR	Age-standardized mortality rate
ASR	Age-standardized incidence rate
BIC	Bayesian information criterion
CI	Confidence interval
CKD	Chronic kidney disease
CVDs	Cardiovascular diseases
DALY	Disability-adjusted life year
EAPC	Estimation of the annual percentage change
ESRD	End-stage renal disease
GBD	Global Burden of Disease
LPA	Low physical activity
NCDs	Noncommunicable diseases
PACF	Partial autocorrelation function
PIs	Prediction intervals
SDI	Sociodemographic index
UI	Uncertainty interval

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12882-025-04117-z.

Supplementary Material 1

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Author contributions

J.M. and X.B. conceived and designed the study. Z.Z.Y., H.D.J., and S.R.L. were responsible for database organization, statistical analysis, and drafting the initial manuscript. X.B. revised the manuscript and managed the project. All authors approved the final publication.

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Data availability

The data for this study were sourced from GBD 2021. GBD 2021 provides the latest and most comprehensive assessment of 369 diseases and 87 associated risk factors globally, covering data from 1990--2021. This study examined the impact of low physical activity on the burden of chronic kidney disease (CKD), including data on deaths, age-standardized mortality rates (ASMRs), disability-adjusted life years (DALYs), and age-standardized DALY rates (ASDRs), all of which were obtained from an online data platform (https://vizhub.healthdata.org/gbd-results/).

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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