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Global trends of chronic kidney disease from 1990 to 2021: a systematic analysis for the global burden of disease study 2021

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Abstract

Background Chronic kidney disease (CKD) is a significant global public health issue. However, the burden of CKD by etiology and trends over time remains inadequately studied.

Methods Data from the Global Burden of Disease Study 2021 (GBD 2021) were analyzed, including cases by region, etiology, age, and sex. Metrics included age-standardized incidence rate (ASIR), age-standardized mortality rate (ASMR), age-standardized prevalence rate (ASPR), disability-adjusted life years (DALYs), and age-standardized DALYs rate (ASDR) between 1990 and 2021. The Joinpoint regression analysis was used to calculate the average annual percentage change (AAPC), and age-period-cohort (APC) analysis was performed to assess trends.

Results In 2021, CKD posed a substantial global burden, with 673,722,703 cases and 19,935,038 new cases. The incidence rate was 233.6 with an AAPC of 0.634. CKD caused 1,527,639 deaths, corresponding to a mortality rate of 18.5 and an AAPC of 0.745. DALYs associated with CKD totaled 44,453,684, with an AAPC of 0.322. CKD burden was primarily attributed to diabetes mellitus type 2 (DMT2), hypertension, and unspecified causes, affecting individuals aged 50 years and older. ASIR and ASPR were higher among females, while males had higher ASMR and ASDR. At regional and national levels, the incidence of CKD was positively correlated with the socio-demographic index (SDI), while mortality, DALYs, and prevalence negatively correlated with SDI. APC analysis revealed an elevated mortality risk (Net Drift = 0.3), increasing with age and over successive periods. Birth cohort analysis indicated higher mortality risks among individuals born after 1992.

Conclusion The global burden of CKD continued to rise due to aging populations, increasing risk factors, and improved detection. While some regions showed success in reducing CKD mortality, widening disparities demanded urgent attention. Early-stage disease and modifiable risks offered prevention opportunities, but realizing this required sustained healthcare investment, especially in resource-limited settings. Therefore, coordinated efforts addressing both risk factors and disease management would be essential to reduce its growing burden.

Keywords Average annual percentage change, Age-period-cohort analysis, Chronic kidney disease, Global disease burden, Joinpoint regression analysis

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Introduction

Chronic kidney disease has emerged as a significant public health concern, exacerbated by population growth and aging demographics, with a global prevalence exceeding 697.5 million cases as of 2017 [1]. According to the GBD study, there were 18,986,903 new cases of CKD reported in 2019 [2]. CKD is associated with an elevated risk of accelerated cardiovascular disease and progression to end-stage renal disease (ESRD), a severe complication characterized by a poor prognosis. ESRD necessitates costly renal replacement therapies, such as dialysis or transplantation, which adversely impact individual's quality of life and contribute substantially to the global disease burden [3]. In 2021, CKD ranked as the 11th leading cause of age-standardized mortality globally [4]. In light of the substantial global health burden posed by CKD, numerous countries have undertaken initiatives to enhance public awareness, formulate prevention and intervention strategies, and deliver comprehensive care for CKD [5].

The GBD 2017 study examined the incidence, mortality, DALYs, causes, and risk factors associated with CKD on global, regional, and national scales [1]. Building on this, the GBD 2019 study employed the estimated annual percentage change (EAPC) to assess CKD incidence and DALYs and its four primary causes across different age groups [2]. However, previous research has not comprehensively analyzed the causes, prevalence, incidence, mortality, and DALYs of CKD. Furthermore, the Coronavirus disease 2019 (COVID-19) pandemic from 2019 to 2021 significantly affected CKD patients, underscoring the necessity of analyzing global CKD trends [6]. Unlike the EAPC method used in the GBD 2019, the AAPC adopted in this study allowed for multiple inflection points in the data, enabling a more flexible capture of nonlinear trends [7]. Additionally, APC analysis facilitated the examination of the effects of age, period, and birth cohort on disease mortality risk [8]. Consequently, this study employed AAPC and APC analyses to evaluate CKD data from GBD 2021, enhancing the understanding of trend changes and providing robust data support for CKD prevention, treatment, and health policy decision-making.

Methods

Study design

This study was aimed to estimate the global burden of CKD through analysis of AAPC and APC. Data from the GBD 2021 were analyzed, including cases by region, nation, etiology, age, and sex. Metrics included age-standardized incidence rate, age-standardized mortality rate, age-standardized prevalence rate, disability-adjusted life years, and age-standardized DALYs rate from 1990 to 2021.

Setting

Data on incidence, mortality, DALYs and prevalence rates for all CKD populations in global, 5 SDI regions, 21 GBD regions, and 204 countries and territories from 1990 to 2021 were collected from GBD 2021.

Participants

The current study population was the CKD population from 1990 to 2021. The burden of CKD for each of the five causes (diabetes mellitus type 1 (DMT1), diabetes mellitus type 2 (DMT2), glomerulonephritis, hypertension, and a residual category of other and unspecified causes) was estimated in this study. The international classification of disease codes and diagnostic criteria for CKD are shown in Tables 1 and 2.

Variables

The number and rate of prevalence, incidence, mortality, and DALYs of CKD were used in this study. The definition of the measure used in this study was shown in Table 3.

The Joinpoint regression analysis was performed to calculate the AAPC. AAPC is a summary measure of the trend over a pre-specified fixed interval. The specified time interval is considered for assigning weights to the length of each segment. The formula of AAPC is as follows: $AAPC = \{\exp\left(\frac{\sum wibi}{\sum wi}\right) - 1\} \times 100$, in which wi indicates the length of each segment in the range of years, while the bi is the slope coefficient for each segment in the desired range of years.

SDI is calculated by GBD to reflect the social and economic determinants that can affect individual health outcomes in countries and regions. SDI was included in the analysis to determine the association between trends of CKD and levels of development. All countries and regions were grouped into five categories according to SDI: Low SDI, Low Middle SDI, Middle SDI, High Middle SDI, and High SDI (Additional file S1: Table S1).

The APC analysis was applied to assess the effects of age, period, and cohort effects on risk of death [8]. In the APC model, net drift indicates the overall annual percentage change across the whole study period, whereas local drift indicates the annual percentage changes in the mortality rate for each age group relative to the net drift. The age effect is the effect of the change in the mortality of disease with age. The period effect refers to the change in the mortality and population of diseases affected by human factors. The cohort effect refers to changes in the mortality of disease due to different levels of exposure to risk factors in different generations of populations.

Table 1 Chronic kidney disease aetiology categories and corresponding ICD 9/10 codes in GBD

	ICD 9 code	ICD 10 code
CKD	585.1, 585.2, 585.3, 585.4, 585.5, 585.9, 403	N18.1, N18.2, N18.3, N18.4, N18.5, N18.6, N18.9
CKD due to Type 1 diabetes	250.41, 250.43	E10.2, E10.21, E10.22, E10.29
CKD due to Type 2 diabetes	250.40, 250.42	E11.2, E11.21, E11.22, E11.29
CKD due to Glomerulonephritis	581, 581.0, 581.1, 581.2, 581.3, 581.8, 581.81, 581.89, 581.9, 582, 582.0, 582.1, 582.2, 582.4, 582.8, 582.81, 582.89, 582.9, 583, 583.0, 583.1, 583.2, 583.4, 583.6, 583.7, 583.8, 583.81, 583.89, 583.9	N02, N02.0, N02.1, N02.2, N02.3, N02.4, N02.5, N02.6, N02.7, N02.8, N02.9, N03, N03.0, N03.1, N03.2, N03.3, N03.4, N03.5, N03.6, N03.7, N03.8, N03.9, N04, N04.0, N04.1, N04.2, N04.3, N04.4, N04.5, N04.6, N04.7, N04.8, N04.9, N05, N05.0, N05.1, N05.2, N05.3, N05.4, N05.5, N05.6, N05.7, N05.8, N05.9, N06, N06.0, N06.1, N06.2, N06.3, N06.4, N06.5, N06.6, N06.7, N06.8, N06.9
CKD due to Hypertension	403, 403.0, 403.00, 403.01, 403.1, 403.10, 403.11, 403.6, 403.9, 403.90, 403.91, 404, 404.0, 404.00, 404.01, 404.02, 404.03, 404.1, 404.10, 404.11, 404.12, 404.13, 404.9, 404.90, 404.91, 404.92, 404.93	I12, I12.0, I12.1, I12.2, I12.9, I13, I13.0, I13.1, I13.10, I13.11, I13.2, I13.9
CKD due to Other and unspecified causes	589, 589.0, 589.1, 589.9, 753.0, 753.1, 753.10, 753.11, 753.12, 753.13, 753.14, 753.15, 753.16, 753.17, 753.19, 753.2, 753.20, 753.21, 753.22,	N07, N07.0, N07.1, N07.2, N07.3, N07.4, N07.5, N07.6, N07.7, N07.8, N07.9, N08, N08.0, N08.1, N08.2, N08.3, N08.4, N08.5, N08.8, N15.0,
CKD due to Other and unspecified causes	753.23, 753.29, 753.3, 283.11, 710.0, 753.0, 753.21, 753.22, 753.29	Q61, Q61.0, Q61.00, Q61.01, Q61.02, Q61.1, Q61.11, Q61.19, Q61.2, Q61.3, Q61.4, Q61.5, Q61.8, Q61.9, Q62, Q62.0, Q62.1, Q62.10, Q62.11, Q62.12, Q62.2, Q62.3, Q62.31, Q62.32, Q62.39, Q62.4, Q62.5, Q62.6, Q62.60, Q62.61, Q62.62, Q62.63, Q62.69, Q62.7, Q62.8, D59.3, M31.31, M32.14, M32.15, N11.9, N13.70, N13.8, Q60.2, Q63.8, N14.0, N14.1, N14.3, N25.89, N26.9, N28.0

Table 2 The diagnostic criteria of chronic kidney disease in GBD

Quantity of interest	Definition
Stages 1&2 chronic kidney disease	Albumin to creatinine ratio (ACR) of ≥ 30 mg/g and estimated glomerular filtration rate (eGFR) > 60 mL/min/1.73m^2 as estimated using the CKD-EPI equation for individuals age > 18 and the Schwartz equation for those < 18.
Stage 3 chronic kidney disease	eGFR 30–60 mL/min/1.73m^2 as estimated using the CKD-EPI equation for individuals age > 18 and the Schwartz equation for those < 18 not on renal replacement therapy.
Stage 4 chronic kidney disease	eGFR 15–30 mL/min/1.73m^2 as estimated using the CKD-EPI equation for individuals age > 18 and the Schwartz equation for those < 18 not on renal replacement therapy.
Stage 5 chronic kidney disease	eGFR < 15 mL/min/1.73m^2 as estimated using the CKD-EPI equation for individuals age > 18 and the Schwartz equation for those < 18 not on renal replacement therapy.
End-stage renal disease(ESDR) after transplant	Received a kidney transplant due to end-stage renal disease. Includes all kidney transplants due to ESRD, not just preemptive transplants. Received dialysis (hemodialysis or peritoneal dialysis) for > 90 days.

CKD is defined as a permanent loss of kidney function as indicated by eGFR and ACR. Moreover, the clinical case definition for CKD is the following: A chronic, progressive condition of the kidney, lasting 3 months or more, with a loss in its key function to filtrate blood to produce urine. The CKD-EPI eGFR equation is considered our gold standard for those 18 years or older and the Schwartz equation is our gold standard for those younger than 18. The formula of CKD-EPI 2009 is as follows: $\mathrm{eGFR} = 141 \times \min(\mathrm{S_{cr}}/\kappa, 1)^{-1.209} \times 0.993^{\mathrm{Age}} \times 1.018$[if female] $\times 1.159$[if Black]. (κ is 0.7 for females and 0.9 for males. α is -0.329 for females and −0.411 for males, where min indicates the minimum of $\mathrm{S_{cr}}/\kappa$ or 1, and max indicates the maximum of $\mathrm{S_{cr}}/\kappa$ or 1.) The formula of Schwartz is as follows: eGFR = 0.413 $\times$ (height/Scr) if height is expressed in centimetres OR 41.3 x (height/Scr) if height is expressed in metres

Data sources

The data of GBD 2021 is open source and accessible for anyone (https://vizhub.healthdata.org/gbd-results/). The APC analysis web tool is available online (https://analysistools.cancer.gov/apc/).

Bias

To enable meaningful comparisons of incidence between different populations worldwide, the same standardized population was used in the GBD study. Age standardization was used to adjust the incidence of different risk factors in a country or region. Therefore, the age-standardized rate (ASR) was obtained based on the Segi-Doll world reference population.

Statistical methods

The prevalence, incidence, mortality, and DALYs were processed by R software (version 4.4.1) and listed with a 95% uncertainty interval (UI). All rates in this study were adjusted to the world population (per 1000,000) [9]. Trends of ASIR, ASMR, ASDR, and ASPR and *P*-value were tracked using the Joinpoint regression analysis and reported as AAPC with 95% confidence intervals (CI). A trend was considered decreasing if AAPC was negative and the 95%CI did not include zero. Positive AAPC

Table 3 The definition of multiple metrics used in the study

Measure	Number	percent	rate
Incidence	Number of new cases in the population	Proportion of new cases of a particular cause relative to cases from all causes	New cases per 100,000 population
ASIR (age-standardized incidence rate)		Proportion of new cases of a particular cause relative to cases from all causes adjusted to the world population	New cases adjusted to the world population (per 100,000)
Mortality	Number of deaths in the population	Proportion of deaths for a particular cause relative to deaths from all causes	Deaths per 100,000 population
ASMR (age-standardized mortality rate)		Proportion of deaths for a particular cause relative to deaths from all causes adjusted to the world population	Deaths adjusted to the world population (per 100,000)
Disability adjusted life years (DALYs) = YLLs + YLDs	Number of DALYs in the population	Proportion of DALYs for a particular cause relative to DALYs for all causes	DALYs per 100,000 population
Years of life lost (YLLs)	Number of YLLs in the population	Proportion of YLLs for a particular cause relative to YLDs for all causes	YLLs per 100,000 population
Years lived with disability (YLDs)	Number of YLDs in the population	Proportion of YLDs for a particular cause relative to YLDs for all causes	YLDs per 100,000 population
ASDR (age-standardized DALYs rate)		Proportion of DALYs for a particular cause relative to DALYs for all causes adjusted to the world population	DALYs adjusted to the world population (per 100,000)
Prevalence	Total number of cases in the population	Proportion of total cases of a particular cause relative to cases from all causes	Total cases per 100,000 population
ASPR (age-standardized prevalence rate)		Proportion of total cases of a particular cause relative to cases from all causes adjusted to the world population	Total cases adjusted to the world population (per 100,000)
AAPC(average annual percentage change)		The average annual increase or decrease in the trend of the indicators(incidence, mortality, DALYs, and prevalence) over a period of time	

and 95% CI indicated increasing trend. $P < 0.05$ suggested that the AAPC had an upward or downward trend rather than just random fluctuations. The analysis was conducted using Joinpoint (version 5.3.0) and R software. A smoothed spline model was used to evaluate the relationship between CKD burden and SDI in 21 regions and 204 countries and territories. Expectations were determined by calculations that take SDI and incidence at all locations into account. Smooth splines were fitted using a locally weighted scatterplot smoothing method that automatically determined the degree, number, and location of nodes based on data and span parameters. Spearman correlation analysis was used to estimate the r-index and p-value of the correlation between ASIR and SDI, between ASMR and SDI, between ASDR and SDI, and between ASPR and SDI. In terms of APC analysis, the mortality and population of CKD from 1992 to 2021 at the age range from 0 to 5 years to 95 + years old were applied to the APC analysis every 5 years (data from 1990 to 1991 were not considered because there were insufficient years for a complete 5-year period). Wald's chi-square was used to test the significance of estimable parameters and functions. For period and cohort effects, the rate ratio > 1 indicated a higher mortality rate of the disease. In this study, $p < 0.05$ was considered statistically significant.

Data processing method

In this study, R software was used for data cleaning, calculations, graphical plotting, and visualizations. R packages of tidyverse, patchwork, scales, dplyr, ggplot2, and ggsci were used in this study. Joinpoint regression analysis was applied to calculate the AAPC. Final editing was done using Adobe Illustrator software 2025 (version CS5).

Results

The trends in incidence, prevalence, dalys, and mortality

The trend of incidence in CKD

In 2021, it was estimated that there were 19,935,038 (95% UI, 18,702,793 to 21,170,794) new cases of CKD reported worldwide, corresponding to an ASIR of 233.6 (95% UI, 220.0 to 247.2) (Table 4). Between 1990 and 2021, the AAPC in the global incidence rate of CKD increased by 0.634 (95% CI, 0.621 to 0.646) per year (Table 4; Fig. 1 A). This global rise in incidence was predominantly attributed to other and unspecified causes (81.21%, 16,188,381/19,935,038), DMT2 (10.09%,2,012,025/19,935,038), and hypertension (6.43%,

Table 4 The number and age standard incidence rate of chronic kidney disease in 1990 and 2021, and joinpoint analysis from 1990 to 2021

		Year 1990		Year 2021		AAPC[4] (95%CI)	*P* -value [5]	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI [1])	ASIR[2] (95%CI[3])	Number (95%UI)	ASIR (95%CI)			Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC
Global		7,790,705 (7226165–8402568)	192.2 (178.7-207.3)	19,935,038 (18702793–21170794)	233.6 (220-247.2)	0.634 (0.621–0.646)	< 0.001	1990-1994	0.65	1994-2001	0.55	2001-2004	0.71	2004-2007	0.59	2007-2019	0.44	2019-2021	0.44
Gen-der	Male	3,385,072 (3133504–3642480)	180.9 (168-195.4)	8,806,346 (8248899–9359371)	220.1 (207.1-233.1)	0.639 (0.615–0.662)	< 0.001	1990-1994	0.73	1994-1999	0.48	1999-2011	0.67	2011-2015	0.8	2015-2021	0.55		
	Female	4,405,633 (4083071–4760087)	201.9 (187.7-218.5)	11,128,691 (10445862–11806798)	246 (231.8-260.7)	0.641 (0.63–0.653)	< 0.001	1990-2002	0.594	2002-2015	0.672	2015-2019	0.806	2019-2021	0.4				
type of CKD	DMT1[7]	63,601 (52476–76375)	1.1 (0.9–1.3)	95,140 (82237–111471)	1.3 (1.1–1.5)	0.59 (0.537–0.643)	< 0.001	1990-1995	-0.043	1995-2000	0.949	2000-2005	0.211	2005-2010	0.811	2015-2021	0.266		
	DMT2[8]	753,106 (680930–826928)	19.1 (17.3–20.8)	2,012,025 (1857800–2154288)	23.1 (21.4–24.7)	0.617 (0.598–0.637)	< 0.001	1990-1994	0.782	1994-2000	0.411	2000-2015	0.64	2015-2019	0.758	2019-2021	0.366		
		Year 1990		Year 2021		ASIR	*P* -value [5]	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI [1])	ASIR[2] (95%CI[3])	Number (95%UI)	AAPC[4] (95%CI)	(95%CI)		Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC
type of CKD	GN[9]	244,229 (218811–271857)	4.3 (3.9–4.7)	357,288 (329226–388483)	4.8 (4.4–5.3)	0.394 (0.361–0.427)	< 0.001	1990-2000	0.293	2000-2005	0.015	2005-2010	0.57	2010-2014	0.78	2014-2021	0.462		
	Hyper-ten-sion	463,924 (426189–505831)	12.2 (11.3–13.3)	1,282,205 (1195230–1366296)	15 (14-15.9)	0.654 (0.638–0.669)	< 0.001	1990-1994	0.72	1994-2000	0.572	2000-2004	0.741	2004-2016	0.662	2016-2019	0.747	2019-2021	0.399
	Other and un-speci-fied causes	6,265,844 (5808707–6762739)	155.4 (144.1-167.9)	16,188,381 (15192359–17180106)	189.4 (178.2-200.6)	0.641 (0.628–0.654)	< 0.001	1990-1994	0.649	1994-2000	0.588	2000-2010	0.666	2010-2019	0.708	2019-2021	0.466		
Re-gion	South-east Asia	466,174 (432763–502980)	156.4 (144.9-169.3)	1,568,475 (1457741–1685245)	231.3 (215.5-247.3)	1.277 (1.249–1.306)	< 0.001	1990-1994	1.946	1994-2005	0.92	2005-2010	1.769	2010-2019	1.281	2019-2021	0.671		
		Year 1990		Year 2021		ASIR	*P* -value [5]	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI [1])	ASIR[2] (95%CI[3])	Number (95%UI)	AAPC[4] (95%CI)	(95%CI)		Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC

Table 4 (continued)

		Year 1990		Year 2021		AAPC[4] (95%CI)	P -value [5]	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI [1])	ASIR[2] (95%CI[3])	Number (95%UI)	ASIR (95%CI)			Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC
Region	Oceania	5052 (4665–5452)	127.6 (117.6-138.5)	15,011 (13905–16088)	162.8 (151.1-174.5)	0.788 (0.757–0.819)	< 0.001	1990-1994	1.054	1994-2000	0.42	2000-2005	0.032	2005-2010	1.359	2010-2021	0.979		
	East Asia	1,331,855 (1207022–1453259)	149.1 (135.8-163.1)	3,505,756 (3245783–3750967)	166.6 (156-176.8)	0.339 (0.289–0.39)	< 0.001	1990-1994	-1.692	1994-2006	0.719	2006-2021	0.584						
	South Asia	1,016,075 (938359–1099033)	146.2 (134.7-158.7)	2,755,183 (2545113–2967871)	177.6 (164.1–192)	0.628 (0.539–0.717)	< 0.001	1990-1992	3.7	1992-1995	1.759	1995-2004	-0.051	2004-2015	0.685	2015-2019	-0.457	2019-2021	0.854
	Western Sub-Saharan Africa	155,997 (145849–167785)	136 (125.9-147.1)	455,812 (426702–486021)	179.8 (165.4-194.2)	0.888 (0.808–0.969)	< 0.001	1990-1994	0.837	1994-2003	0.008	2003-2006	0.586	2006-2010	2.159	2010-2021	1.255		
		Year 1990		Year 2021		ASIR (95%CI)	P -value [5]	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI [1])	ASIR[2] (95%CI[3])	Number (95%UI)	AAPC[4] (95%CI)			Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC
Region	Southern Sub-Saharan Africa	52,502 (48770–56528)	169.1 (156.5-183.9)	142,811 (132638–152029)	233.6 (216.7-248.7)	1.043 (0.976–1.111)	< 0.001	1990-1994	2.003	1994-2002	-0.173	2002-2006	0.472	2006-2010	1.617	2010-2018	1.919	2018-2021	0.711
	Central Sub-Saharan Africa	28,155 (26057–30337)	94.5 (86.8–103)	88,402 (82071–94885)	130.5 (120.3-142.1)	1.052 (1.023–1.081)	< 0.001	1990-1994	0.761	1994-2006	0.115	2006-2021	1.886						
	Eastern Sub-Saharan Africa	94,221 (87688–101006)	94.9 (87.6–103)	244,189 (228098–260057)	118.1 (109-127.6)	0.711 (0.677–0.744)	< 0.001	1990-1995	0.673	1995-2005	-0.328	2005-2015	1.211	2015-2021	1.656				
	Tropical Latin America	194,244 (179335–210104)	192.8 (176.8-209.5)	663,468 (620124–707786)	259.3 (242.9-275.6)	0.96 (0.923–0.997)	< 0.001	1990-2000	1.364	2000-2005	0.165	2005-2010	1.491	2010-2015	0.902	2015-2019	-0.155	2019-2021	2.007

Table 4 (continued)

		Year 1990		Year 2021		AAPC[4] (95%CI)	P-value [5]	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI [1])	ASIR[2] (95%CI[3])	Number (95%UI)	ASIR (95%CI)			Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC
		Year 1990		Year 2021		ASIR	P-value [5]	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI [1])	ASIR[2] (95%CI[3])	Number (95%UI)	AAPC[4] (95%CI)	(95%CI)		Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC
Region	Andean Latin America	36,900 (33960–40277)	161.5 (147.7-177.3)	177,934 (165435–192798)	298.2 (276.2-322.6)	2.023 (1.975–2.07)	< 0.001	1990-1995	1.435	1995-1999	2.554	1999-2005	3.303	2005-2012	2.019	2012-2019	1.636	2019-2021	0.008
	Central Latin America	266,579 (245613–291023)	275.6 (252.2-302.1)	1,056,443 (1000773–1110306)	411.4 (390.2-431.3)	1.329 (1.295–1.364)	< 0.001	1990-2011	1.665	2011-2019	0.786	2019-2021	-0.006						
	Caribbean	46,852 (43426–50526)	168.8 (156-183.6)	145,322 (136425–154427)	274.2 (257.5-291.9)	1.589 (1.561–1.617)	< 0.001	1990-1999	1.827	1999-2005	2.383	2005-2010	1.872	2010-2015	0.815	2015-2019	1.171	2019-2021	0.229
	North Africa and Middle East	482,950 (445183–524328)	255.3 (235.3–278)	1,988,923 (1863403–2127840)	411.2 (385.4-438.4)	1.558 (1.483–1.634)	< 0.001	1990-1993	3.084	1993-1996	1.633	1996-2005	0.759	2005-2010	2.449	2010-2014	1.813	2014-2021	1.131
		Year 1990		Year 2021		ASIR	P-value [5]	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI [1])	ASIR[2] (95%CI[3])	Number (95%UI)	AAPC[4] (95%CI)	(95%CI)		Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC
Region	Central Asia	64,439 (59475–69705)	114.2 (105.1-124.9)	168,442 (154020–183300)	187.3 (173.8-201.6)	1.62 (1.579–1.661)	< 0.001	1990-1994	1.696	1994-2001	0.347	2001-2005	1.604	2005-2012	2.693	2012-2019	2.331	2019-2021	-0.218
	Central Europe	193,169 (174647–213352)	132.3 (120.8-145.3)	458,516 (423618–495453)	218.4 (203.4-234.1)	1.635 (1.597–1.672)	< 0.001	1990-1992	5.177	1992-1995	2.995	1995-1999	1.368	1999-2005	1.905	2005-2019	1.081	2019-2021	-0.246
	Eastern Europe	277,461 (253751–306742)	108.4 (100.3–118)	548,051 (501351–595627)	180.1 (167.5-193.2)	1.662 (1.627–1.697)	< 0.001	1990-1996	1.446	1996-1999	2.192	1999-2006	0.94	2006-2018	2.25	2018-2021	0.911		
	Western Europe	1,328,467 (1221423–1459692)	223.9 (207.1-244.1)	2,271,237 (2122275–2425621)	238.6 (223.9-254.3)	0.216 (0.191–0.241)	< 0.001	1990-1997	0.291	1997-2005	0.641	2005-2016	-0.036	2016-2019	0.301	2019-2021	-0.48		
		Year 1990		Year 2021		ASIR	P-value [5]	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI [1])	ASIR[2] (95%CI[3])	Number (95%UI)	AAPC[4] (95%CI)	(95%CI)		Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC

Table 4 (continued)

		Year 1990		Year 2021		AAPC[4] (95%CI)	P -value [5]	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI [1])	ASIR[2] (95%CI[3])	Number (95%UI)	ASIR (95%CI)			Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC
Region	Southern Latin America	97,990 (89314–107374)	212.8 (194.9-232.3)	244,517 (224582–263090)	281.7 (260.5-302.5)	0.915 (0.89–0.94)	< 0.001	1990-1993	0.866	1993-1996	1.184	1996-2004	1.902	2004-2009	1.028	2009-2019	0.401	2019–2021	-1.027
	High-income North America	29,949 (27171–31434)	8.3 (7.6–8.7)	143,679 (124827–154757)	20.6 (18.1–22)	3.011 (2.739–3.283)	< 0.001	1990-1998	1.075	1998-2004	0.588	2004-2007	4.08	2007-2010	0.495	2010-2021	0.99		
	High-income Asia Pacific	22,233 (20303–23333)	12.6 (11.3–13.3)	63,459 (50432–70953)	9.7 (8.1–10.7)	-0.895 (-1.226 - -0.562)	< 0.001	1990-1997	0.43	1997-2012	0.107	2012-2015	1.124	2015-2018	0.162	2018-2021	1.048		
	Australasia	62,421 (59023–66438)	259.2 (245.7-274.3)	160,661 (146984–172346)	297.3 (274.5-317.6)	0.452 (0.425–0.479)	< 0.001	1990-1996	0.214	1996-2005	0.991	2005-2015	-0.108	2015-2019	1.197	2019-2021	0.074		
		Year 1990		Year 2021		ASIR (95%CI)	P -value [5]	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI [1])	ASIR[2] (95%CI[3])	Number (95%UI)	AAPC[4] (95%CI)			Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC
SDI[10]	Low SDI	348,934 (324143–375458)	121.7 (112.8-132.3)	950,557 (888494–1011543)	155 (143.4-167.3)	0.774 (0.739–0.808)	< 0.001	1990-1994	1.508	1994-2005	-0.009	2005-2012	1.345	2012-2021	0.965				
	Low-middle SDI	1,107,201 (1026640–1198009)	153.1 (141.4-166.4)	3,130,960 (2912350–3362301)	205 (189.8-220.3)	0.941 (0.875–1.006)	< 0.001	1990-1992	3.059	1992-1995	1.65	1995-2005	0.221	2005-2010	1.436	2010-2014	1.066	2014-2021	0.648
	Middle SDI	1,963,348 (1808277–2127370)	171.2 (157.7-185.8)	6,251,147 (5866964–6655539)	233 (219.5-246.1)	1.002 (0.987–1.017)	< 0.001	1990-1993	0.783	1993-2006	1.009	2006-2009	1.509	2009-2015	1.121	2015-2019	0.603	2019-2021	0.971
	High-middle SDI	1,574,444 (1447925–1709190)	160.4 (148.1-174.1)	3,917,149 (3653537–4175391)	205.9 (194.1-218.6)	0.813 (0.79–0.835)	< 0.001	1990-1994	0.076	1994-2004	1.119	2004-2014	0.914	2014-2018	0.754	2018-2021	0.523		

Table 4 (continued)

	Year 1990		Year 2021		AAPC[4] (95%CI)	*P*-value[5]	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
	Number (95%UI[1])	ASIR[2] (95%CI[3])	Number (95%UI)	ASIR (95%CI)			Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC
	Year 1990		Year 2021	ASIR	*P*-value[5]		Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
	Number (95%UI[1])	ASIR[2] (95%CI[3])	Number (95%UI)	AAPC[4] (95%CI)	(95%CI)		Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC
SDI[10] High SDI	2,789,648 (2576788–3024433)	252.3 (234.2-272.4)	5,666,653 (5273251–6033381)	277.7 (260.7–295)	0.313 (0.29–0.337)	<0.001	2000-2005	0.61	2005-2010	-0.444	2010-2015	0.311	2015-2019	1.066	2019-2021	-0.347		

1: UI=uncertainty interval. 2: ASIR=age-standardized incidence rate adjusted to the world population (per 1000,000). 3: CI=confidence intervals. 4: AAPC=average annual percentage change calculated by Joinpoint regression analysis; AAPC>0 indicated an upward trend, and AAPC<0 indicated a downward trend. 5: *P*-value was calculated by Joinpoint regression analysis; *P*<0.05 showed that the trend suggested by the AAPC was significant. 6:APC=annual percent change, APC was significantly different from 0 (two-side *p*<0.05). 7: DMT1=diabetes mellitus type 1. 8.DMT2=diabetes mellitus type 2. 9.GN=glomerulonephritis. 10.SDI=socio-demographic index

1,282,205/19,935,038) (Table 4). In 2021, Central Latin America reported the highest ASIR of CKD at 411.4 (95%UI, 390.2 to 431.3) per 100,000 population (Table 4). From 1990 to 2021, the most significant increases in the AAPC incidence rate of CKD were observed in Andean Latin America (AAPC = 2.023 [95%CI: 1.975 to 2.070]), Eastern Europe (AAPC = 1.662 [1.627 to 1.697]), and Central Europe (AAPC = 1.635 [1.597 to 1.672]) (Table 4; Fig. 2 A). At the national level, Saudi Arabia exhibited the highest ASIR of CKD at 495.8 (95%UI, 465.1 to 529.6). All countries and territories demonstrated an increase in ASIR exceeding 100. Estonia reported the highest AAPC in ASIR of CKD, with an AAPC of 2.375 (95% CI, 2.322 to 2.429) (Additional file S1: Table S2; Fig. 2 A).

The trends of mortality in CKD

In 2021, the number of deaths attributable to CKD was 1,527,639 (95%UI, 408,407,762 to 485,084,462), with an ASMR of 18.5 (95%UI, 16.7 to 19.9) (Table 5). The AAPC in CKD mortality increased by 0.745 (95% CI, 0.603 to 0.886) per year globally from 1990 to 2021 (Table 5; Fig. 1B). The global rise in mortality was primarily attributable to DMT2 (31.24%, 477,273/1,527,639), hypertension (29.74%, 454,359/1,527,639), and other and unspecified causes (20.16%, 307,990/1,527,639) (Table 5). The Central Sub-Saharan Africa exhibited the highest ASMR of CKD, with a rate of 43.7 (95%UI [33.3 to 56.3]) (Table 5). Between 1990 and 2021, the most significant increases in the AAPC in CKD mortality rates were observed in High-income North America (AAPC = 3.011 [95%CI, 2.739 to 3.283]) and Central Asia (AAPC = 2.816 [95%CI, 1.339 to 4.315]) (Table 5; Fig. 2B). At the national level, Mauritius exhibited the highest ASMR of 80.1 (95%UI, 74.1 to 84.6), with an AAPC of 1.568 (95%CI, 0.681 to 2.464). Across 204 countries and territories, there was an observed increasing trend in ASMR, ranging from 9 to 80.1. Ukraine reported the highest AAPC in ASMR for CKD, with an AAPC of 9.456 (95%CI, 6.804 to 12.174), whereas Kuwait demonstrated the largest decrease in AAPC for ASMR of CKD, with an AAPC of -2.356 (95% CI, -3.912 to -0.774) (Additional file S1: Table S3; Fig. 2B).

The trend of dalys in CKD

In 2021, the global burden of CKD, measured in DALYs, amounted to 44,453,684 with the ASDR of 529.6 (Additional file1: Table S4). Between 1990 and 2021, the AAPC in the DALYs rate for CKD increased by 0.322 (95%CI, 0.262 to 0.383) globally (Additional file 1: Table S4; Fig. 1 C). This global rise in DALYs was primarily attributed to DMT2 (25.37%, 11,278,935/44,453,684), hypertension (24.41%, 10,850,728/44,453,684), and other and unspecified causes (24.41%, 10,850,728/44,453,684) (Additional file1: Table S4). The Eastern Sub-Saharan Africa region exhibited the highest ASDR for CKD, with a rate of 948.4

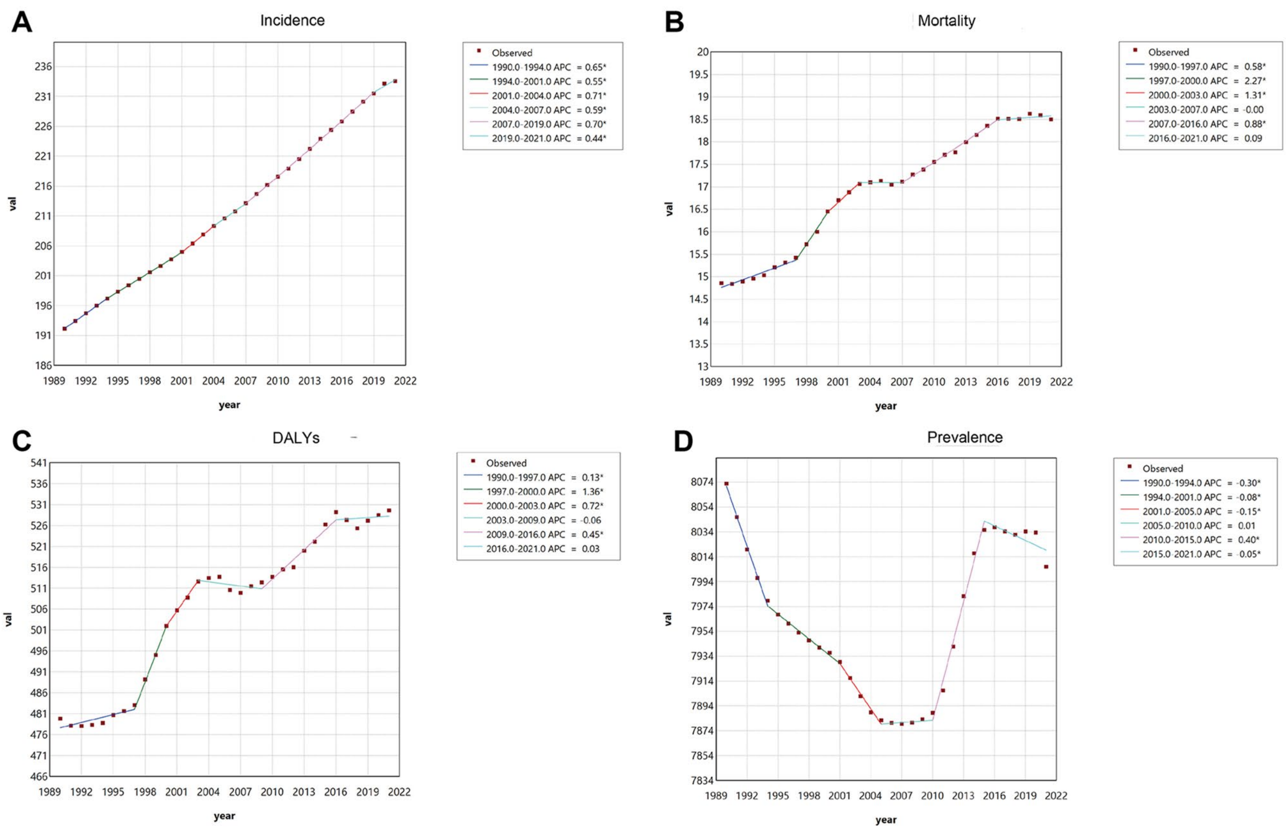

Fig. 1 AAPC of CKD in incidence, mortality, DALYs, and prevalence rates, globally, 1990–2021. (**A**) AAPC of CKD in incidence from 1990 to 2021. (**B**) AAPC of CKD in mortality from 1990 to 2021. (**C**) AAPC of CKD in DALYs from 1990 to 2021. (**D**) AAPC of CKD in prevalence from 1990 to 2021

(95%UI, 838.7 to 1090.4) (Additional file 1: Table S4). From 1990 to 2021, the most significant increase in the AAPC of DALYs rates for CKD was observed in High-income North America, with an AAPC of 2.107 (95%CI, 1.883 to 2.332) (Additional file 1:Table S4; Fig. 2 C). For the national level, Mauritius showed the highest ASDR of 2196.1 (95%UI, 2043.1 to 2318.9). 204 countries and territories indicated an increasing trend in ASDR from 171.8 to 2196.1. El Salvador reported the highest AAPC in ASDR of CKD (AAPC = 3.076 [95%CI, 2.768 to 3.384]), while Kuwait showed the largest decreases of AAPC in ASDR of CKD (AAPC=-2.369 [95%CI, -3.655 to -1.066]) (Additional file S1: Table S5; Fig. 2 C).

The trend of prevalence in CKD

The total number of CKD cases was 673,722,703 (95%UI, 629,095,119 to 722,364,095), with an ASPR of 8006.0 (95%UI,7482.1 to 8575.6) (Additional file 1: Table S6). The AAPC prevalence rate of CKD decreased by an average of -0.021 (95% CI, -0.039 to -0.002) per year globally between 1990 and 2021 (Additonal file 1: Table S6; Fig. 1D). Despite the negative growth in AAPC, the number of people with CKD worldwide remained large. It was mainly caused by DMT2 (15.97%, 107,559,955/673,722,703) and other and unspecified causes (77.87%, 524,663,971 /673,722,703) (Additional file 1: Table S6). Central Asia exhibited the highest ASPR of CKD, measured at 10,698.2 (95%UI, 10,022.9 to 11,348.1) (Table S6). The most significant increases in the AAPC in CKD prevalence rates were observed in Andean Latin America (AAPC = 0.100 [95%CI, 0.091 to 0.108]) and Southern Latin America (AAPC = 0.101 [95%CI, 0.087 to 0.115]). Conversely, East Asia experienced the largest decrease in the AAPC of CKD prevalence, with a rate of -0.388 (95% CI, -0.463 to -0.313) (Additional file 1: Table S6; Fig. 2D). For the national level, Mauritius showed the highest ASPR of 11411.6 (95%UI, 10649.1 to 12263.7). 204 countries and territories indicated an increasing trend in ASPR from 4368.8 to 11411.6. Italy reported the highest AAPC in ASPR of CKD (AAPC = 0.304 [95%CI, 0.287 to 0.320]), while China demonstrated the largest decreases of AAPC in ASPR of CKD (AAPC=-0.396 [95%CI, -0.473 to -0.318]) (Additional file 1: Table S7; Fig. 2D).

The differences in age, sex, causes, and regions in CKD

The differences in age, sex, and causes in CKD

In the GBD 2021 study, CKD was attributed to five primary etiologies: DMT1, DMT2, glomerulonephritis,

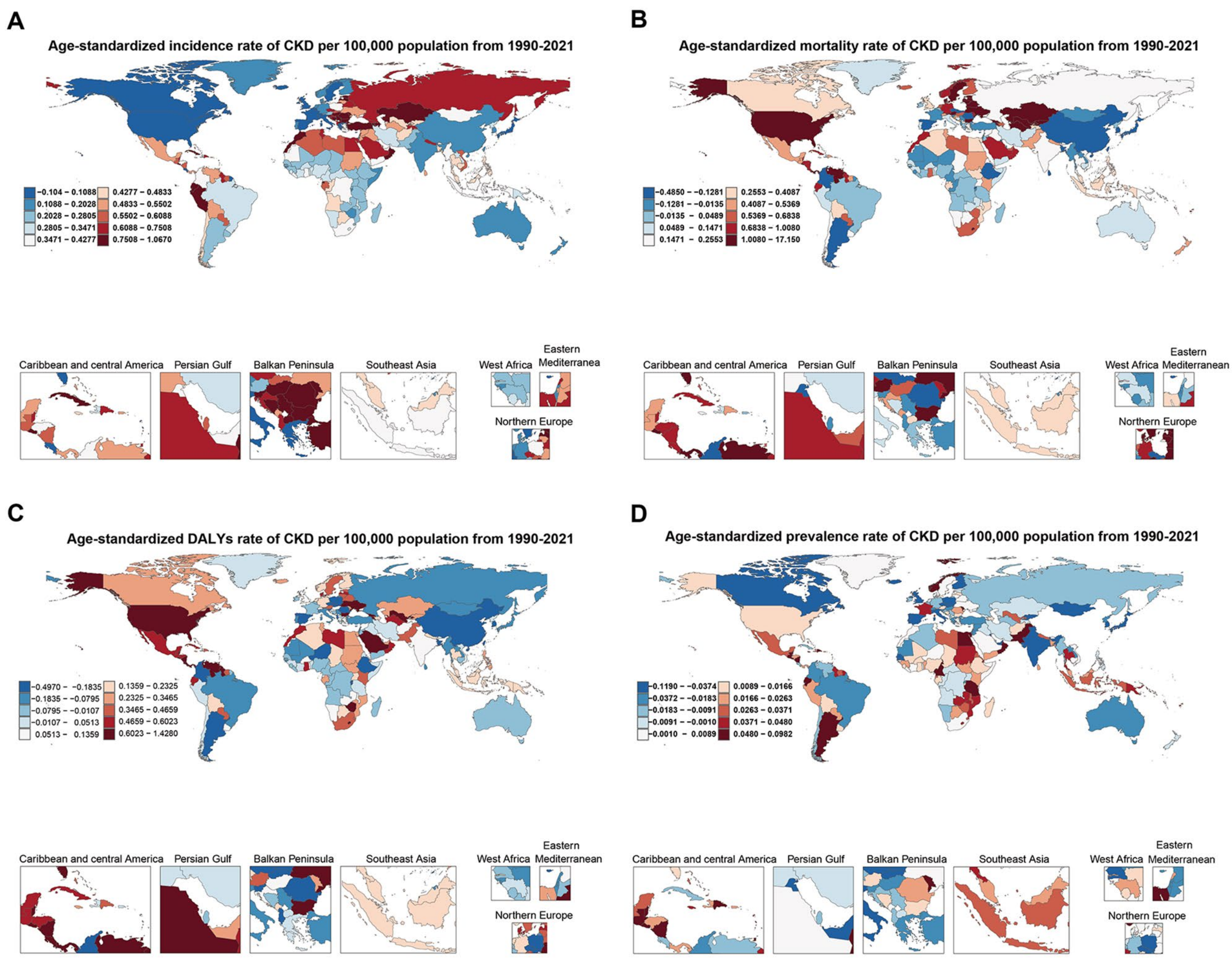

Fig. 2 Age-standardized incidence, mortality, DALYs, and prevalence rates of CKD from 1990 to 2021. (**A**) Age-standardized incidence rate of CKD from 1990 to 2021. (**B**) Age-standardized mortality rate of CKD from 1990 to 2021. (**C**) Age-standardized DALYs rate of CKD from 1990 to 2021. (**D**) Age-standardized prevalence rate f CKD in prevalence from 1990 to 2021

hypertension, and a residual category encompassing other and unspecified causes. The ASIR of CKD was predominantly observed within the 50–84 age demographic. Notably, the incidence was higher among females compared to males, primarily due to CKD resulting from other and unspecified causes, as well as DMT2 (Fig. 3 A & Additional file 2: Figure S1). The ASMR for CKD predominantly occurred within the 50-89year age group, with a higher mortality observed in males compared to females. The primary etiologies were CKD resulting from hypertension, DMT2, and other and unspecified causes (Fig. 3B & Additional file 2: Figure S2). Similarly, the ASDR for CKD was primarily concentrated in the 50-79year age group, again with a greater number in males than females, and was chiefly attributed to CKD due to hypertension, DMT2, and other and unspecified causes (Fig. 3 C & Additional file 2: Figure S3). The ASPR of CKD was mainly observed within the 30–84 age demographic. Notably, the prevalence was higher among females compared to males, primarily due to CKD resulting from other and unspecified causes, as well as DMT2 (Fig. 3D & Additional file 2: Figure S4).

The discrepancy in regions of CKD

At the regional level, the ASIR and ASPR of CKD exhibited similar trends across the 21 GBD regions, primarily attributable to CKD resulting from DMT2, hypertension, and other and unspecified causes (Additional file 2: Figure S5A&B). On a global scale, the ASMR of CKD was predominantly influenced by CKD associated with hypertension, DMT2, and other and unspecified causes (Additional file 2: Figure S5C). The mortality rate in Andean Latin America was predominantly attributed to CKD resulting from hypertension and DMT2. In Eastern Sub-Saharan Africa, mortality was primarily due to CKD caused by glomerulonephritis. In Oceania, the mortality rate was mainly associated with CKD resulting from both DMT1 and DMT2. Mortality in Eastern Sub-Saharan

Table 5 The number and age standard mortality rate of chronic kidney disease in 1990 and 2021, and joinpoint analysis from 1990 to 2021

		Year 1990		**Year 2021**		**AAPC[4]**	***P***	**Trend1**		**Trend2**		**Trend3**		**Trend4**		**Trend5**		**Trend6**	
		Number (95%UI[1])	**ASMR[2] (95%CI[3])**	**Number (95%UI)**	**ASMR (95%CI)**	**(95%CI)**	**value[5]**	**Period**	**APC[6]**	**Period**	**APC**	**Period**	**APC**	**Period**	**APC**	**Period**	**APC**	**Period**	**APC**
Global		552,673 (513463–607915)	14.9 (13.6–16.4)	1,527,639 (1389377–1638914)	18.5 (16.7–19.9)	0.745 (0.603–0.886)	< 0.001	1990-1997	0.50	1997-2000	2.27	2000-2003	1.31	2003–2003	-0.041	2007-2016	0.88	2016-2021	0.0 9
Gender	Male	291,666 (259303–334444)	18.1 (16.3–21)	794,519 (719354–856326)	21.9 (19.7–23.6)	0.637 (0.544–0.73)	< 0.001	1990-1996	0.385	1996-2003	1.484	2003-2007	0.007	2007-2016	0.864	2016-2021	-0.319		
	Female	261,007 (237127–287997)	12.6 (11.4–14)	733,120 (654830–795633)	15.9 (14.2–17.3)	0.773 (0.624–0.921)	< 0.001	1990-1997	0.641	1997-2000	2.641	2000-2003	1.263	2003-2007	-0.143	2007-2017	0.705	2017-2021	-0.242
type of CKD	DMT1[7]	49,300 (39088–61208)	1.1 (0.8–1.4)	94,020 (71457–119984)	1.1 (0.8–1.4)	0.026 (-0.087–0.138)	0.655	1990-1997	0.033	1997–2000	1.004	2000–2004	0.04	2004–2007	-1.362	2007-2012	-0.36	2012-2021	0.3 7
		Year 1990		Year 2021		AAPC[4]	*P*	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI[1])	ASMR[2] (95%CI[3])	Number (95%UI)	ASMR (95%CI)	(95%CI)	value[5]	Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC
type of CKD	DMT2[8]	147,970 (124179–176413)	4.2 (3.5–4.9)	477,273 (401541–565951)	5.7 (4.8–6.8)	1.069 (0.928–1.209)	< 0.001	1990–1997	0. 912	1997-2001	2.48	2001-2004	1.381	2004-2007	-0.076	2007-2015	1.394	2015-2021	0.306
	GN[9]	83,170 (69625–97738)	2 (1.7–2.4)	193,997 (162332–226569)	2.3 (2-2.7)	0.499 (0.412–0.587)	< 0.001	1990-1997	0.366	1997-2001	1.672	2001-2006	-0.012	2006-2012	0.357	2012-2016	1.089	2016-2021	-0.03
	Hyper-tension	148,983 (123167–176985)	4.3 (3.6–5.1)	454,359 (381291–524688)	5.5 (4.7–6.4)	0.868 (0.779–0.957)	< 0.001	1990-1997	0.659	1997-2002	2.14	2002-2007	0.304	2007-2016	1.047	2016-2021	0.143		
	Other and unspecified causes	123,249 (104874–140205)	3.3 (2.8–3.8)	307,990 (259417–357326)	3.8 (3.2–4.4)	0.468 (0.344–0.593)	< 0.001	1990-1993	-0.317	1993-1997	0.831	1997-2001	2.226	2001-2013	0.241	2013-2016	0.757	2016-2021	-0.367
		Year 1990		Year 2021		AAPC[4]	*P*	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI[1])	ASMR[2] (95%CI[3])	Number (95%UI)	ASMR (95%CI)	(95%CI)	value[5]	Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC

Table 5 (continued)

		Year 1990		Year 2021		AAPC[4] (95%CI)	*P* value[5]	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI[1])	ASMR[2] (95%CI[3])	Number (95%UI)	ASMR (95%CI)			Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC
Region	Southeast Asia	57,881 (52199–66490)	22.9 (20.6–26.7)	170,033 (148864–190537)	28.5 (24.8–31.9)	0.743 (0.636–0.851)	< 0.001	1990-2005	0.988	2005-2010	0.578	2010–2013	-0.17	2013–2021	0.733				
	Oceania	489 (342–661)	17.2 (12.8–23.1)	1546 (1265–1892)	21.6 (18-26.4)	0.715 (0.57–0.86)	< 0.001	1990–2001	1.699	2001–2010	-0.07	2010–2019	0.678	2019–2021	-0.944				
	East Asia	107,701 (94477–126024)	14.4 (12.7–17)	217,342 (178047–259057)	11.1 (9.2–13.2)	-0.867 (-1.037 - -0.696)	< 0.001	1990–1998	-1.063	1998–2004	0.588	2004–2007	-4.08	2007–2010	0.495	2010–2021	-0.99		
	South Asia	79,714 (68086–89404)	14 (12.1–15.9)	226,043 (192546–264155)	16.5 (14-19.3)	0.584 (0.242–0.928)	0.001	1990-1997	1.365	1997-2000	-1.299	2000–2007	0.309	2007–2011	-1.167	2011–2014	3.53	2014–2021	0.662
		Year 1990		Year 2021		AAPC[4] (95%CI)	*P* value[5]	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI[1])	ASMR[2] (95%CI[3])	Number (95%UI)	ASMR (95%CI)			Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC
Region	Western Sub-Saharan Africa	28,294 (24259–32687)	33.6 (29-39.2)	64,796 (53512–76124)	36.4 (31.1–42.8)	0.26 (0.173–0.349)	< 0.001	1990-1994	1.343	1994-1997	0.247	1997-2001	-0.253	2001-2008	0.127	2008-2016	0.407	2016-2021	-0.228
	Southern Sub-Saharan Africa	5376 (4674–6619)	20.9 (18-26.2)	17,365 (15612–19485)	34.4 (31.1–38.3)	1.65 (1.194–2.108)	< 0.001	1990-1995	2.986	1995-1998	6.936	1998-2004	2.849	2004-2016	0.551	2016-2021	-1.496		
	Central Sub-Saharan Africa	8667 (7200–10419)	42.7 (35.5–51)	21,011 (16114–27467)	43.7 (33.3–56.3)	0.08 (0.02–0.139)	0.009	1990-1998	0.121	1998-2007	-0.79	2007-2021	0.618						
	Eastern Sub-Saharan Africa	30,615 (26919–35172)	42.4 (37.1–50.2)	60,918 (53817–69935)	40.1 (35.6–46)	-0.168 (-0.251 - -0.086)	< 0.001	1990-1993	0.408	1993-1998	-0.099	1998-2009	-0.865	2009-2015	-0.003	2015-2021	0.607		

Table 5 (continued)

		Year 1990		Year 2021		AAPC[4] (95%CI)	*P* value[5]	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI[1])	ASMR[2] (95%CI[3])	Number (95%UI)	ASMR (95%CI)			Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC
		Year 1990		Year 2021		AAPC[4]	*P*	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI[1])	ASMR[2] (95%CI[3])	Number (95%UI)	ASMR (95%CI)	(95%CI)	value[5]	Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC
Region	Tropical Latin America	15,524 (14832–16076)	17.9 (16.9–18.7)	46,925 (42508–49438)	18.8 (17-19.9)	0.259 (-0.324–0.845)	0.385	1990-1994	-0.366	1994-2000	2.663	2000-2004	-0.826	2004-2007	-2.626	2007-2010	1.747	2010-2021	-0.017
	Andean Latin America	5795 (5288–6456)	28.5 (25.9–31.9)	21,619 (17903–25800)	37.7 (31.3–44.9)	1.086 (0.683–1.49)	< 0.001	1990-2002	3.097	2002-2012	0.272	2012-2015	-3.659	2015-2021	0.894				
	Central Latin America	22,182 (21513–22820)	27.9 (26.8–28.8)	104,444 (94171–116461)	42.4 (38.3–47)	1.107 (0.521–1.695)	< 0.001	1990-1996	0.319	1996-1999	10.196	1999-2009	2.559	2009-2016	-0.616	2016-2021	-3.51		
	Caribbean	4754 (4399–5437)	18.7 (17.3–21.3)	13,888 (12086–16193)	25.8 (22.4–30.1)	1.1 (0.859–1.343)	< 0.001	1990-1996	-1.658	1996-2001	3.695	2001-2008	0.96	2008-2014	2.281	2014-2021	0.802		
		Year 1990		Year 2021		AAPC[4]	*P*	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI[1])	ASMR[2] (95%CI[3])	Number (95%UI)	ASMR (95%CI)	(95%CI)	value[5]	Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC
Region	North Africa and Middle East	45,472 (37703–66491)	31.2 (25.5–47)	144,687 (126153–162699)	37.7 (32.7–42.4)	0.682 (0.578–0.786)	< 0.001	1990-2005	-0.156	2005-2016	1.853	2016-2021	0.647						
	Central Asia	2536 (2250–2933)	5 (4.4–5.9)	9397 (8278–10515)	12.1 (10.7–13.5)	2.816 (1.339–4.315)	< 0.001	1990-1992	18.336	1992-2002	3.259	2002-2005	9.469	2005-2014	-0.916	2014-2017	2.746	2017-2021	-1.645
	Central Europe	14,335 (13732–14892)	10.5 (10-10.9)	21,635 (19445–23977)	9.4 (8.4–10.5)	-0.282 (-0.738–0.175)	0.226	1990-1994	-1.909	1994-2002	-0.236	2002-2007	1.782	2007-2011	-1.125	2011-2014	-4.442	2014-2021	1.462
	Eastern Europe	9389 (9183–9574)	3.6 (3.5–3.7)	17,821 (16126–19853)	5.2 (4.7–5.8)	1.271 (0.265–2.288)	0.013	1990-1994	7.27	1994-1997	-5.426	1997-2000	3.347	2000-2012	-1.221	2012-2017	6.753	2017-2021	0.006

Table 5 (continued)

		Year 1990		Year 2021		AAPC[4] (95%CI)	P value[5]	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI[1])	ASMR[2] (95%CI[3])	Number (95%UI)	ASMR (95%CI)			Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC
		Year 1990		Year 2021		AAPC[4] (95%CI)	P value[5]	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI[1])	ASMR[2] (95%CI[3])	Number (95%UI)	ASMR (95%CI)			Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC
Region	Western Europe	48,662 (44430–50877)	8.3 (7.5–8.7)	133,481 (109637–148166)	10.7 (8.9–11.8)	0.883 (0.604–1.162)	< 0.001	1990-1992	-3.856	1992-1997	0.287	1997-2002	4.425	2002-2009	-0.046	2009-2015	2.461	2015-2021	-0.372
	Southern Latin America	11,256 (10698–11760)	26 (24.6–27.2)	21,583 (19510–22986)	23.8 (21.6–25.4)	-0.28 (-0.84–0.282)	0.328	1990-1992	2.253	1992-1995	-2.38	1995-1998	4.911	1998-2002	2.142	2002-2019	-1.054	2019-2021	-5.25
	High-income North America	29,949 (27171–31434)	8.3 (7.6–8.7)	143,679 (124827–154757)	20.6 (18.1–22)	3.011 (2.739–3.283)	< 0.001	1990-1994	10.336	1994-2002	4.259	2002-2014	9.469	2014-2017	-0.916	2017-2021	-1.245		
	High-income Asia Pacific	22,233 (20303–23333)	12.6 (11.3–13.3)	63,459 (50432–70953)	9.7 (8.1–10.7)	-0.895 (-1.226 - -0.562)	< 0.001	1990-1994	-2.909	1994-2002	-1.236	2002-2007	1.782	2007-2011	-1.125	2011-2021	-3.442		
		Year 1990		Year 2021		AAPC[4] (95%CI)	P value[5]	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI[1])	ASMR[2] (95%CI[3])	Number (95%UI)	ASMR (95%CI)			Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC
Region	Australasia	1851 (1687–1959)	8.5 (7.7-9)	5968 (5025–6525)	9.6 (8.2–10.5)	0.341 (-0.497–1.186)	0.426	1990-1997	-0.966	1997-2012	1.729	2012-2015	4.342	2015-2021	-3.457				
SDI[10]	Low SDI	64,656 (57360–73648)	29.7 (26.3–34.6)	136,797 (118867–157579)	29.4 (26.1–33.8)	-0.007 (-0.143–0.128)	0.914	1990-1996	0.374	1996-2008	-0.82	2008-2011	0.328	2011-2014	2.392	2014-2021	-0.095		
	Low-middle SDI	110,899 (98721–127673)	18.6 (16.4–22.2)	309,509 (280315–349455)	23.1 (21-26.3)	0.732 (0.564–0.901)	< 0.001	1990-1997	1.118	1997-2004	0.64	2004-2012	0.326	2012-2015	1.74	2015-2019	0.82	2019-2021	-0.336
	Middle SDI	177,302 (162783–198065)	19.1 (17.4–21.3)	513,051 (458865–556752)	20.9 (18.4–22.7)	0.319 (0.199–0.438)	< 0.001	1990-1995	0.175	1995-2001	1.445	2001-2010	0.299	2010-2021	-0.209				
		Year 1990		Year 2021		AAPC[4] (95%CI)	P value[5]	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI[1])	ASMR[2] (95%CI[3])	Number (95%UI)	ASMR (95%CI)			Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC

Table 5 (continued)

		Year 1990		Year 2021		AAPC[4] (95%CI)	P value[5]	Trend1		Trend2		Trend3		Trend4		Trend5		Trend6	
		Number (95%UI[1])	ASMR[2] (95%CI[3])	Number (95%UI)	ASMR (95%CI)			Period	APC[6]	Period	APC	Period	APC	Period	APC	Period	APC	Period	APC
SDI[10]	High-middle SDI	99,196 (91758–110668)	11.4 (10.4–12.6)	226,797 (201672–252703)	12 (10.7–13.4)	0.21 (0.039–0.382)	0.016	1990-1997	0.261	1997-2003	1.57	2003-2007	-0.901	2007-2013	-0.227	2013-2016	1.133	2016-2021	-0.607
	High SDI	100,025 (92113–104189)	9.2 (8.5–9.6)	340,083 (289016–369665)	14.1 (12.3–15.2)	1.441 (1.204–1.677)	<0.001	1990-1994	-0.504	1994-1998	1.307	1998-2001	5.747	2001-2009	0.726	2009-2013	3.2	2013-2021	0.754

1:UI = uncertainty interval. 2:ASMR = age-standardized mortality rate adjusted to the world population(per 1000,000). 3: CI = confidence intervals. 4:AAPC = average annual percentage change calculated by Joinpoint regression analysis; AAPC > 0 indicated an upward trend, and AAPC < 0 indicated a downward trend. 5: *P*-value was calculated by Joinpoint regression analysis; *P* < 0.05 showed that the trend suggested by the AAPC was significant. 6:APC = annual percent change, APC was significantly different from 0 (two-side *p* < 0.05). 7: DMT1 = diabetes mellitus type 1 8.DMT2 = diabetes mellitus type 2 9.GN = glomerulonephritis. 10.SDI = socio-demographic index

Africa was also significantly influenced by CKD due to DMT2 and glomerulonephritis. In North Africa and the Middle East, the mortality rate was primarily due to CKD caused by hypertension, as well as other and unspecified causes (Additional file 2: Figure S5C). Globally, the ASDR for CKD was predominantly attributed to CKD resulting from hypertension, DMT2, and other and unspecified causes (Additional file 2: Figure S5D). In Central Latin America, the DALYs rate was primarily associated with CKD due to other and unspecified causes and glomerulonephritis. In Central Asia, North Africa, and the Middle East, the DALYs rate was largely attributed to CKD from other and unspecified causes. In Southeast Asia and the regions of Sub-Saharan Africa (Western, Central, and Southern), the DALYs rate was mainly due to CKD induced by hypertension. In Oceania, the primary contributors to the DALYs rate were CKD resulting from hypertension and DMT2. In Eastern Sub-Saharan Africa, the DALYs rate was predominantly attributed to CKD caused by glomerulonephritis (Additional file 2: Figure S5D).

The relationship of SDI and CKD

The relationship of SDI and CKD at the regional level

At the regional level, the ASIR of CKD showed an exponential increase with rising SDI (Fig. 4A). Regions such as Central and Tropical Latin America, High-income North America, and Australasia exhibited higher-than-expected ASIR relative to their SDI from 1990 to 2021. A positive correlation was observed between ASIR and SDI ($r = 0.59$, $p < 0.001$) across regions (Fig. 4A). Conversely, negative correlations were identified between ASMR and SDI (r=-0.635, $p < 0.001$) (Fig. 4B), ASDR and SDI (r=-0.719, $p < 0.001$) (Fig. 4C), and between ASPR and SDI (r=-0.254, $p < 0.001$) (Fig. 4D). The regions of Sub-Saharan Africa (Central and southern) and Latin America (Andean, central, and tropical) exhibited higher-than-anticipated ASMR for CKD relative to their SDI (Fig. 4B). Similarly, the regions of Sub-Saharan Africa (Central and southern) and Latin America (Andean and central) demonstrated elevated ASDR for CKD, surpassing expectations based on their SDI (Fig. 4C). Furthermore, the regions of Sub-Saharan Africa (Central and southern), Asia (Central, south, and southeast), North Africa and the Middle East, and Eastern Europe showed higher-than-expected ASPR of CKD according to their SDI (Fig. 4D).

The relationship of SDI and CKD at the national level

At the national level, the ASIR of CKD demonstrated an exponential increase in conjunction with rising SDI. In 2021, Saudi Arabia, Qatar, and the United Arab Emirates exhibited higher-than-anticipated ASIR relative to their SDI. A positive correlation was observed between

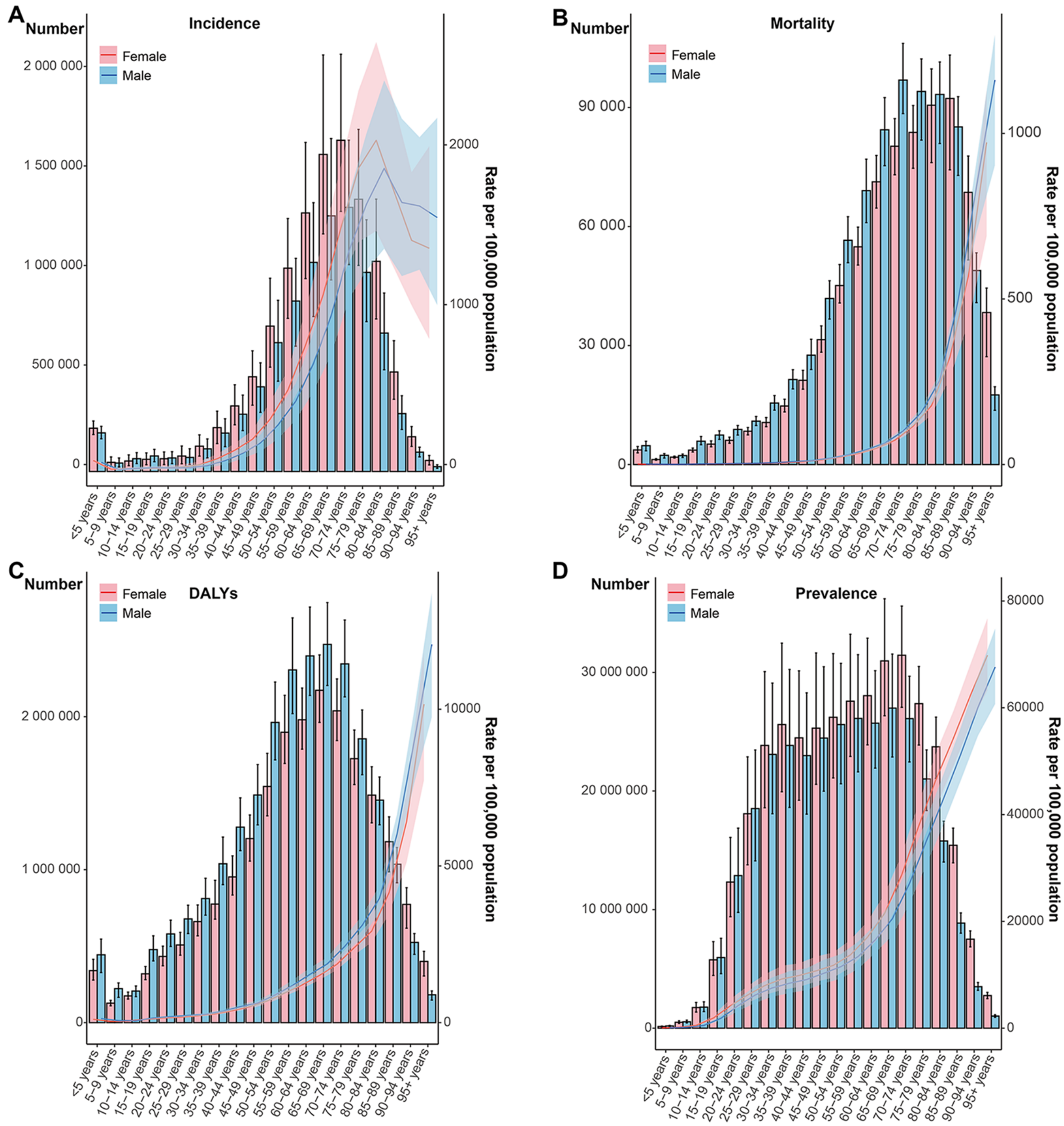

Fig. 3 The difference of sex and age in age-standardized incidence, mortality, DALYs, and prevalence rates of CKD, globally, in 2021. (**A**) The difference of sex and age in number and age-standardized incidence rate of CKD. (**B**) The difference of sex and age in number and age-standardized mortality rate of CKD; (**C**) The difference of sex and age in number and age-standardized DALYs rate of CKD; (**D**) The difference of sex and age in number and age-standardized prevalence rate of CKD

ASIR and SDI ($r = 0.429$, $p < 0.001$), as illustrated in Fig. 5A. Conversely, negative correlations were identified between the ASMR and SDI ($r = -0.541$, $p < 0.001$) (Fig. 5B), between the ASDR and SDI ($r = -0.6$, $p < 0.001$) (Fig. 5C), and between the ASPR and SDI ($r = -0.199$, $p = 0.01$) (Fig. 5D). Saudi Arabia, Mauritius, and American Samoa exhibited ASMR for CKD that exceeded expectations based on their SDI (Fig. 5B). Similarly, Mauritius, American Samoa, and Saudi Arabia demonstrated higher-than-anticipated ASDR for CKD according to their SDI (Fig. 5C). Furthermore, Mauritius, the Republic of Moldova, and Uzbekistan showed ASPR for CKD that surpassed expected levels based on their SDI (Fig. 5D).

Net drift and local drift in CKD

Net drift indicates the overall annual percentage change across the whole study period, whereas local drift indicates the annual percentage changes in the mortality rate for each age group relative to the net drift. The overall net drift was similar on CKD (0.3, [95%CI, 0.244 to 0.355]), CKD due to DMT2 (0.473, [95%CI, 0.135 to 0.813]), CKD due to hypertension (0.53, [95%CI, 0.478 to 0.580]),

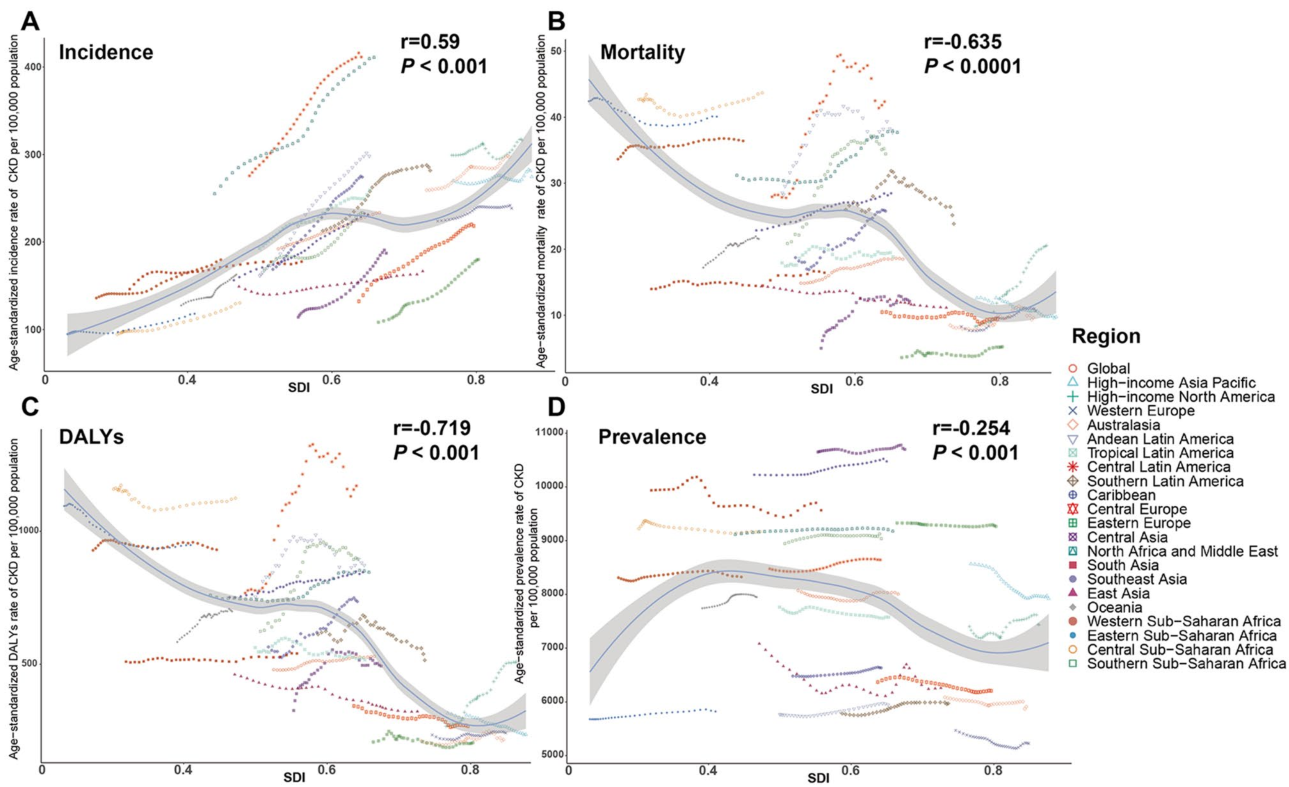

Fig. 4 Age-standardized incidence, mortality, DALYs, and prevalence rates of CKD, globally and for 21 GBD regions, by SDI, 1990–2021. (**A**) The relationship between age-standardized incidence rate of CKD and SDI. (**B**) The relationship between age-standardized mortality rate of CKD and SDI. (**C**) The relationship between age-standardized DALYs rate of CKD and SDI. (**D**) The relationship between age-standardized prevalence rate of CKD and SDI. Expected values, based on SDI and disease rates in all locations, were shown as a solid line; expected values based on a calculation accounting for the SDI and disease rates across all locations. 31 points were plotted for each region and showed the observed age-standardized incidence, mortality, DALYs or prevalence rates for each year from 1990 to 2021 for that region. The shaded area indicated the 95% CI of the expected values. Points above the solid line represented a higher-than-expected burden, and those below the line showed a lower-than-expected burden

CKD due to glomerulonephritis (0.421, [95%CI, 0.369 to 0.474]), and CKD due to other and unspecified causes (0.321, [95%CI, 0.248 to 0.394]), reflecting substantial increases in mortality of CKD due to DMT2, hypertension, glomerulonephritis, and other and unspecified causes across the study period (Fig. 6 A-E). The overall net drift of CKD due to DMT1 (-0.2, [95%CI, -0.478 to 0.078]) showed the opposite trend, reflecting a substantial reduction in mortality of CKD due to DMT1 across the study period (Fig. 6 F).

Age-period-cohort effects on CKD mortality

The age effects on CKD mortality

Additional file 2: Figure S6-8 showed estimates of age, period, and cohort effects on CKD. Regarding the impact of age on mortality rates, there was a progressive increase in the mortality rate associated with CKD as age advances (Additional file 2: Figure S6A). CKD attributed to DMT2, hypertension, glomerulonephritis, and other and unspecified causes exhibited a comparable pattern (Additional file 2: Figure S6B-E). In contrast, the mortality rate for CKD resulting from DMT1 demonstrated a distinct trajectory (Additional file 2: Figure S6F), beginning to rise at 32.5 years, reaching its peak at 57.5 years, and subsequently declining.

The period effect on CKD mortality

Regarding the period effect, mortality from CKD has shown a gradual increase since 2010 (Additional file 2: Figure S7A). This trend is mirrored in CKD mortality attributable to DMT2, hypertension, glomerulonephritis, and other and unspecified causes, all of which have exhibited a progressive rise in mortality rates post-2005 (Additional file 2: Figure S7B-E). Conversely, CKD associated with DMT1 has displayed an opposite pattern, with a notable improvement in mortality rates after 2005 (Additional file 2: Figure S7F).

Regarding the period effect, mortality from CKD has shown a gradual increase since 2010 (Additional file 2: Figure S7A). This trend is mirrored in CKD mortality attributable to DMT2, hypertension, glomerulonephritis, and other and unspecified causes, all of which have exhibited a progressive rise in mortality rates post-2005 (Additional file 2: Figure S7B-E). Conversely, CKD

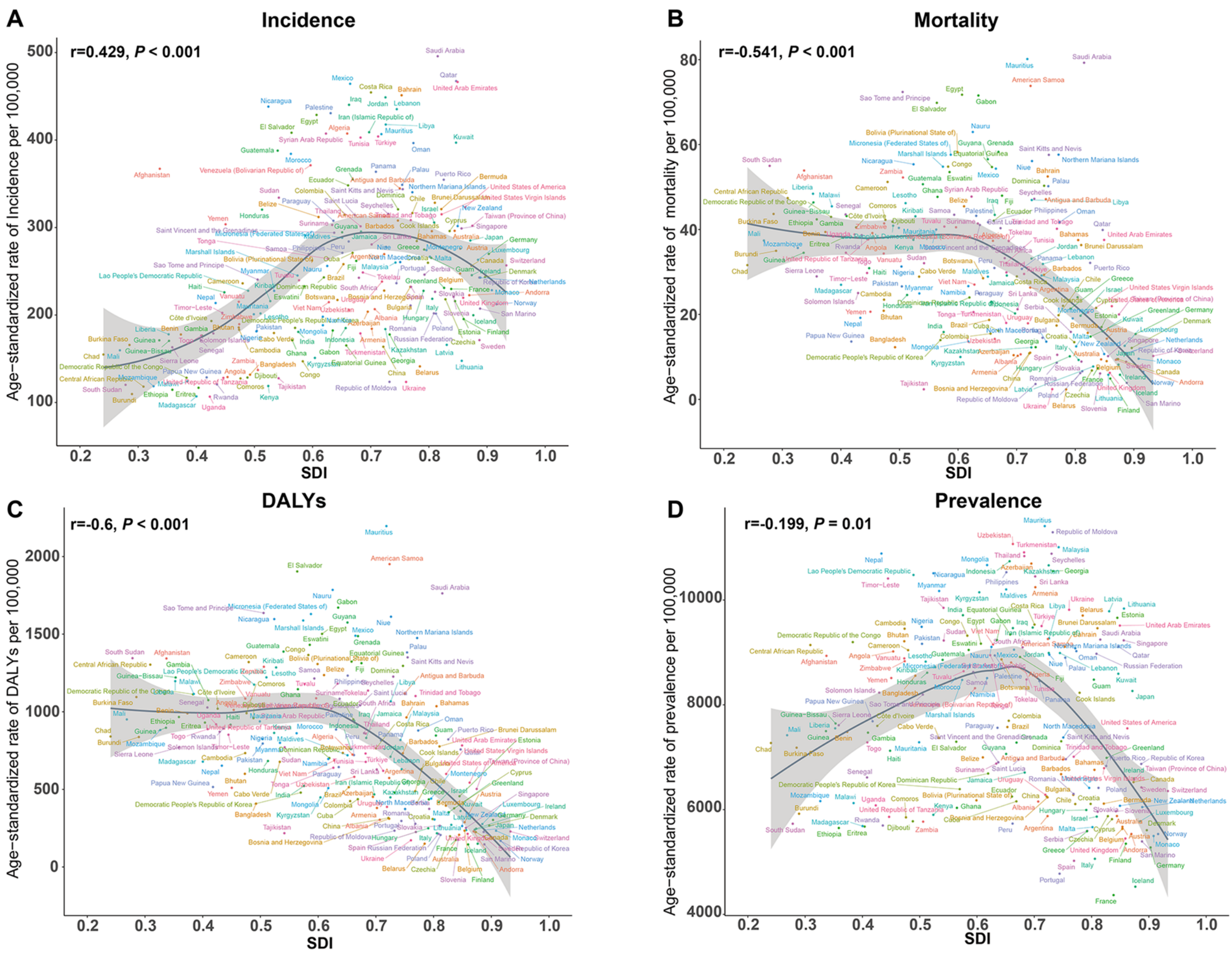

Fig. 5 Age-standardized incidence, mortality, DALYs, and prevalence rates of CKD, globally and for 204 countries and territories, by SDI, in 2021. (**A**) The relationship between age-standardized incidence rate of CKD and SDI. (**B**) The relationship between age-standardized mortality rate of CKD and SDI. (**C**) The relationship between age-standardized DALYs rate of CKD and SDI. (**D**) The relationship between age-standardized prevalence rate of CKD and SDI. Expected values, based on SDI and disease rates in all locations, were shown as a spot; expected values based on a calculation accounting for the SDI and disease rates across all locations. The shaded area indicated the 95% CI of the expected values. Points above the solid line represented a higher-than-expected burden, and those below the line showed a lower-than-expected burden

associated with DMT1 has displayed an opposite pattern, with a notable improvement in mortality rates after 2005 (Additional file 2: Figure S7F).

The birth cohort effect on CKD mortality

In terms of birth cohort effects, the mortality risk associated with CKD was reduced for individuals born prior to 1957, between 1983 and 1991, and after 1992 (Additional file 2: Figure S8A). The birth cohort effect for CKD attributable to hypertension, glomerulonephritis, and other unspecified causes exhibited a bimodal distribution. The analysis of birth cohort effects on the risk of mortality from CKD revealed distinct patterns associated with various etiologies. Specifically, individuals born before 1947 and after 1997 exhibited a reduced risk of death from CKD attributable to hypertension (Additional file 2: Figure S8B). Similarly, the risk of mortality from CKD due to glomerulonephritis was diminished among those born before 1957 and after 2012 (Additional file 2: Figure S8C). Furthermore, a decreased risk of death from CKD resulting from other and unspecified causes was observed in cohorts born before 1957 and after 2002 (Additional file 2: Figure S8D). In contrast, the birth cohort effect for CKD associated with DMT1 or DMT2 presented a continuous trend. Notably, the risk of death from CKD due to DMT1 was lower in individuals born before 1957 and after 1962 (Additional file 2: Figure S8E). The risk of death from CKD due to DMT2 was lower in those born before 1947 and after 1977 (Additional file 2: Figure S8F).

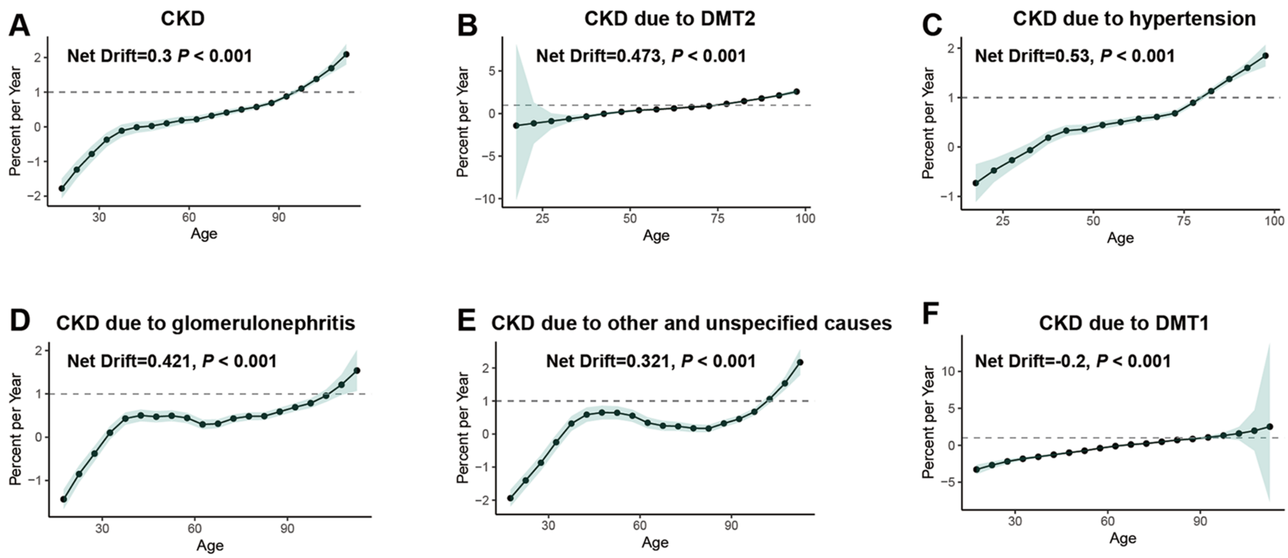

Fig. 6 Local drift with net drift values on CKD and five causes of CKD mortality rate, globally, from 1992 to 2021. Local drift with net drift values for CKD mortality from 1992 to 2021. (**B**) Local drift with net drift values for CKD due to DMT2 mortality from 1992 to 2021. (**C**) Local drift with net drift values for CKD due to hypertension mortality from 1992 to 2021. (**D**) Local drift with net drift values for CKD due to glomerulobephritis mortality from 1992 to 2021. (**E**) Local drift with net drift values for CKD due to other and unspecified causes mortality from 1992 to 2021. (**F**) Local drift with net drift values for CKD due to DMT1 mortality from 1992 to 2021. Net drift represents the overall annual percentage change with the corresponding 95% CI (some were too narrow to show). The values were > 0, indicating substantial increases in mortality across the study period. The values were < 0, indicating substantial reductions in mortality across the study perio

Discussion

Global burden and trends of CKD

CKD represents a significant global public health challenge. In 2021, there were 673,722,703 prevalence cases and 19,935,038 incidence cases globally, with mortality reaching 1,527,639 deaths and DALYs totaling 44,453,683 years. The disease burden was primarily attributed to DMT2, hypertension, and other unspecified causes, predominantly affecting individuals aged 50 years and older. Compared to previous GBD studies, our analysis revealed distinct trends. While GBD 2017 and 2019 reported upward trends in all CKD metrics, our study showed increasing incidence (AAPC 0.634%), mortality (AAPC 0.745%), and DALYs (AAPC 0.322%), but decreasing prevalence (AAPC −0.021%). This discrepancy may reflect the impact of improved case management in high-income regions and methodological improvements in data collection and analysis.

Impact of COVID-19 on CKD burden

The COVID-19 pandemic significantly affected CKD burden patterns. Our analysis of pre- and post-pandemic data (2019 vs. 2021) revealed a 7.3% increase in CKD prevalence in high-income regions, exceeding the pre-pandemic average growth rate of 5.1%. Direct kidney injury occurred in 20–30% of severe COVID-19 patients, with 15–20% potentially developing chronic renal insufficiency [10, 11]. Additionally, pandemic-related disruptions to routine screening and care led to delayed diagnoses and suboptimal management of existing patients [12].

Gender and age-related disparities

Significant gender disparities existed in CKD burden. Females showed higher incidence and prevalence rates, while males exhibited higher mortality and DALYs rates. This differential pattern may be attributed to the protective effects of estrogen versus the potentially detrimental impact of testosterone on renal function [13]. The age-standardized nature of our analysis accounted for differences in muscle mass and serum creatinine levels between genders [14, 15].

Etiological analysis and regional variations

Major risk factors

Hypertension and DMT2 emerged as primary CKD contributors globally. With approximately 1.3 billion people having hypertension and 537 million with diabetes worldwide, these conditions represent critical targets for CKD prevention [16, 17]. Population aging and lifestyle factors (sedentary behavior, poor diet, obesity) contributed to the rising incidence of hypertension and DMT2 [16].

Unspecified causes: a growing concern

CKD due to other and unspecified causes constituted a substantial portion of the global burden, particularly in Central America and South Asia [18]. This category may include cases with unclear diagnoses, multiple coexisting causes, and emerging regional conditions such as chronic interstitial nephritis in agricultural communities [19]. The potential for misclassification bias necessitates cautious interpretation and targeted research in high-prevalence regions.

Regional disease patterns

Sub-Saharan Africa showed high prevalence of CKD due to glomerulonephritis (approximately 15.4%) [20], while Latin American regions demonstrated elevated rates of CKD due to other and unspecified causes. These patterns reflected regional variations in environmental exposures, genetic factors, and healthcare infrastructure.

Socioeconomic determinants and healthcare access

CKD incidence was positively correlated with SDI, while mortality, DALYs, and prevalence negatively correlated with development levels. High-income regions demonstrated superior outcomes through early diagnosis, standardized treatment protocols, and comprehensive health interventions [21]. In contrast, resource-limited settings faced challenges including insufficient healthcare infrastructure, limited access to renal replacement therapy, and high out-of-pocket costs [22, 23]. The Netherlands Kidney Foundation's awareness campaigns demonstrated that increased public awareness correlates with higher CKD detection rates [24]. Similar initiatives in other regions could improve early identification and management.

Age-period-cohort analysis insights

APC analysis revealed increasing mortality risk over time (net drift 0.3%), with distinct patterns across different etiologies. CKD due to DMT1 showed a unique pattern with peak mortality risk at 32.5–57.5 years, reflecting its earlier onset compared to other causes. The analysis also identified varying birth cohort effects, suggesting the influence of generational exposures and healthcare improvements.

Clinical and policy implications

Our findings support several key recommendations: (1) Prevention Focus: Strengthen management of hypertension and diabetes through comprehensive primary care programs. (2) Early Detection: Implement systematic CKD screening in high-risk populations, particularly in diabetes and hypertension patients. (3) Healthcare Infrastructure: Enhance nephrology capacity in resource-limited settings, addressing the shortage of specialists (e.g., 1.2 nephrologists per million population in South Asia [25. (4) Research Priorities: Conduct targeted investigations in regions with high rates of unspecified CKD to identify environmental and occupational risk factors. (5) Global Monitoring: Develop standardized surveillance systems to improve data quality and reduce classification uncertainties.

Future research directions

Future studies should focus on: (1) Investigating emerging risk factors including environmental pollution and climate change; (2) Evaluating cost-effectiveness of innovative interventions; (3) Addressing social determinants of CKD disparities; (4) Developing region-specific prevention strategies; (5) Improving diagnostic criteria and classification systems for CKD due to other and unspecified causes.

Study limitations

This study utilized the comprehensive GBD 2021 dataset covering 204 countries and territories, employed standardized methodological frameworks, and used advanced analytical methods (AAPC and APC analysis) to capture complex temporal trends. Several limitations merit consideration: (1) Heterogeneous data quality across regions, particularly in low-income countries; (2) Potential underestimation due to asymptomatic early-stage disease; (3) Misclassification bias in the "unspecified causes" category.

Conclusions

The global burden of CKD continued to rise, driven by population aging, increasing prevalence of risk factors, and improved case detection. While some regions showed success in reducing CKD mortality, widening disparities demand urgent attention. The predominance of early-stage disease and modifiable risk factors offered opportunities for prevention, but realizing this potential required sustained investment in healthcare systems, particularly in resource-limited settings. As CKD emerged as a key challenge for global health, coordinated efforts addressing both upstream risk factors and downstream disease management would be essential for reducing its growing burden.

Abbreviations

ASR	Age-standardized rate
ASIR	Age-standardized incidence rate
ASMR	Age-standardized mortality rate
ASPR	Age-standardized prevalence rate
ASDR	Age-standardized DALYs rate
AAPC	Average annual percentage change
APC	Age-period-cohort analysis
BMI	Body mass index
CKD	Chronic kidney disease
CI	Confidence intervals
COVID-19	Coronavirus disease 2019
DALYs	Disability-adjusted life years
DM	Diabetes mellitus
DMT1	Diabetes mellitus type 1
DMT2	Diabetes mellitus type 2
ESRD	End-stage renal disease

EAPC	Estimated annual percentage change
eGFR	Estimated glomerular filtration rate
GBD	Global burden of disease
SDI	Socio-demographic index
UI	Uncertainty interval

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

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Author contributions
Shudong Yang, Renhuan Yu: study concept and supervision; Zhongtang Li: methodology and formal analysis; Riming He: formal analysis; Yuzhi Wang, Ziyi Qu: data curation and validation; Jiahui Li: visualization and validation. Each author contributed important intellectual content during manuscript drafting or revision and agrees to be personally accountable for the individual's own contributions and to ensure that questions pertaining to the accuracy or integrity of any portion of the work, even one in which the author was not directly involved, are appropriately investigated and resolved, including with documentation in the literature if appropriate.

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Data availability
No datasets were generated or analysed during the current study.

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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References

1. GBD Chronic Kidney Disease Collaboration. Global, regional, and national burden of chronic kidney disease, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet [Internet]. 2020 Feb 29 [cited 2024 Dec 6];395(10225):709–33. Available from: http://www.ncbi.nlm.nih.gov/pubmed/32061315
2. Ying M, Shao X, Qin H, Yin P, Lin Y, Wu J et al. Disease Burden and Epidemiological Trends of Chronic Kidney Disease at the Global, Regional, National Levels from 1990 to 2019. Nephron [Internet]. 2024 [cited 2025 Apr 20];148(2):113–23. Available from: http://www.ncbi.nlm.nih.gov/pubmed/37717572
3. Romagnani P, Remuzzi G, Glassock R, Levin A, Jager KJ, Tonelli M et al. Chronic kidney disease. Nat Rev Dis Primers [Internet]. 2017 Nov 23 [cited 2024 Dec6];3:17088. Available from: http://www.ncbi.nlm.nih.gov/pubmed/29168475
4. GBD 2021 Causes of Death Collaborators. Global burden of 288 causes of death and life expectancy decomposition in 204 countries and territories and 811 subnational locations, 1990–2021: a systematic analysis for the Global Burden of Disease Study 2021. Lancet [Internet]. 2024 May 18 [cited 2024 Dec 6];403(10440):2100–32. Available from: http://www.ncbi.nlm.nih.gov/pubmed/38582094
5. Yang CW, Harris DCH, Luyckx VA, Nangaku M, Hou FF, Garcia Garcia G et al. Global case studies for chronic kidney disease/end-stage kidney disease care. Kidney Int Suppl (2011) [Internet]. 2020 Mar [cited 2024 Dec 6];10(1):e24–48. Available from: http://www.ncbi.nlm.nih.gov/pubmed/32149007
6. Long JD, Strohbehn I, Sawtell R, Bhattacharyya R, Sise ME. COVID-19 Survival and its impact on chronic kidney disease. Transl Res [Internet]. 2022 Mar [cited 2024 Dec 6];241:70–82. Available from: http://www.ncbi.nlm.nih.gov/pubmed/34774843
7. Kim HJ, Fay MP, Feuer EJ, Midthune DN. Permutation tests for joinpoint regression with applications to cancer rates. Stat Med [Internet]. 2000 Feb 15 [cited 2025 Apr 21];19(3):335–51. Available from: http://www.ncbi.nlm.nih.gov/pubmed/10649300
8. Rosenberg PS, Check DP, Anderson WF. A web tool for age-period-cohort analysis of cancer incidence and mortality rates. Cancer Epidemiol Biomarkers Prev. 2014;23(11):2296–302.
9. SEGI M, FUJISAKU S. Geographical observation on cancer mortality by selected sites on the basis of standardised death rate. Gan. 1957;48(2):219–25.
10. MK N, LG F, RL M, KD MJC et al. L, M O,. COVID-19-associated acute kidney injury: consensus report of the 25th Acute Disease Quality Initiative (ADQI) Workgroup. Nat Rev Nephrol [Internet]. 2020 [cited 2025 Apr 20];16(12). Available from: http://www.ncbi.nlm.nih.gov/pubmed/33060844
11. Bowe B, Xie Y, Xu E, Al-Aly Z. Kidney Outcomes in Long COVID. J Am Soc Nephrol [Internet]. 2021 Nov [cited 2025 Apr 20];32(11):2851–62. Available from: http://www.ncbi.nlm.nih.gov/pubmed/34470828
12. Chudasama YV, Gillies CL, Zaccardi F, Coles B, Davies MJ, Seidu S et al. Impact of COVID-19 on routine care for chronic diseases: A global survey of views from healthcare professionals. Diabetes Metab Syndr [Internet]. 2020 [cited 2025 Apr 20];14(5):965–7. Available from: http://www.ncbi.nlm.nih.gov/pubmed/32604016
13. Carrero JJ, Hecking M, Chesnaye NC, Jager KJ. Sex and gender disparities in the epidemiology and outcomes of chronic kidney disease. Nat Rev Nephrol [Internet]. 2018 Mar [cited 2024 Dec 6];14(3):151–64. Available from: http://www.ncbi.nlm.nih.gov/pubmed/29355169
14. Eriksen BO, Ingebretsen OC. The progression of chronic kidney disease: a 10-year population-based study of the effects of gender and age. Kidney Int [Internet]. 2006 Jan [cited 2024 Dec 6];69(2):375–82. Available from: http://www.ncbi.nlm.nih.gov/pubmed/16408129
15. Carrero JJ. Gender differences in chronic kidney disease: underpinnings and therapeutic implications. Kidney Blood Press Res [Internet]. 2010 [cited 2024 Dec 6];33(5):383–92. Available from: http://www.ncbi.nlm.nih.gov/pubmed/20948227
16. Schutte AE, Jafar TH, Poulter NR, Damasceno A, Khan NA, Nilsson PM et al. Addressing global disparities in blood pressure control: perspectives of the International Society of Hypertension. Cardiovasc Res [Internet]. 2023 Mar 31 [cited 2024 Dec 6];119(2):381–409. Available from: http://www.ncbi.nlm.nih.gov/pubmed/36219457
17. Ma X, Liu R, Xi X, Zhuo H, Gu Y. Global burden of chronic kidney disease due to diabetes mellitus, 1990–2021, and projections to 2050. Front Endocrinol (Lausanne) [Internet]. 2025 [cited 2025 Apr 22];16:1513008. Available from: http://www.ncbi.nlm.nih.gov/pubmed/40060381
18. Johnson RJ, Wesseling C, Newman LS. Chronic Kidney Disease of Unknown Cause in Agricultural Communities. N Engl J Med [Internet]. 2019 May 9 [cited 2025 Apr 21];380(19):1843–52. Available from: http://www.ncbi.nlm.nih.gov/pubmed/31067373
19. Rao IR, Bangera A, Nagaraju SP, Shenoy SV, Prabhu RA, Rangaswamy D et al. Chronic kidney disease of unknown aetiology: A comprehensive review of a global public health problem. Trop Med Int Health [Internet]. 2023 Aug [cited 2024 Dec 6];28(8):588–600. Available from: http://www.ncbi.nlm.nih.gov/pubmed/37403003
20. O'Shaughnessy MM, Hogan SL, Thompson BD, Coppo R, Fogo AB, Jennette JC. Glomerular disease frequencies by race, sex and region: results from the International Kidney Biopsy Survey. Nephrol Dial Transplant [Internet]. 2018

Apr 1 [cited 2024 Dec 6];33(4):661–9. Available from: http://www.ncbi.nlm.nih.gov/pubmed/29106637

21. Luyckx VA, Cherney DZI, Bello AK, Preventing. CKD in Developed Countries. Kidney Int Rep [Internet]. 2020 Mar [cited 2025 Apr 20];5(3):263–77. Available from: http://www.ncbi.nlm.nih.gov/pubmed/32154448
22. Ashuntantang G, Osafo C, Olowu WA, Arogundade F, Niang A, Porter J et al. Outcomes in adults and children with end-stage kidney disease requiring dialysis in sub-Saharan Africa: a systematic review. Lancet Glob Health [Internet]. 2017 Apr [cited 2024 Dec 6];5(4):e408–17. Available from: http://www.ncbi.nlm.nih.gov/pubmed/28229924
23. Dodd R, Palagyi A, Guild L, Jha V, Jan S. The impact of out-of-pocket costs on treatment commencement and adherence in chronic kidney disease: a systematic review. Health Policy Plan [Internet]. 2018 Nov 1 [cited 2025 Apr 20];33(9):1047–54. Available from: http://www.ncbi.nlm.nih.gov/pubmed/30247548
24. Dorgelo A, Oostrom TAJ. An integrated approach towards a public health perspective on chronic kidney disease. Nat Rev Nephrol [Internet]. 2022 Mar [cited 2025 Apr 21];18(3):131–2. Available from: http://www.ncbi.nlm.nih.gov/pubmed/35087245
25. Bharati J, Jha V. Global Kidney Health Atlas: a spotlight on the Asia-Pacific sector. Kidney Res Clin Pract [Internet]. 2022 Jan [cited 2024 Dec 6];41(1):22–30. Available from: http://www.ncbi.nlm.nih.gov/pubmed/35108769

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