

Projected Health and Economic Burden of Chronic Kidney Disease in China Through 2060: A National and Provincial Modeling Study

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Abstract

Background.

Chronic kidney disease (CKD) is a leading cause of morbidity and mortality in China and worldwide. However, long-term projections of CKD integrating future epidemiological trends with healthcare costs and macroeconomic consequences are lacking. We projected the future health and economic burden of CKD across mainland China and its 31 provinces from 2025 to 2060.

Methods.

We conducted a modeling study integrating epidemiological projections, healthcare cost estimation, and macroeconomic modeling. Age- and sex-specific CKD incidence, prevalence, mortality, years lived with disability (YLDs), years of life lost (YLLs), and disability-adjusted life years (DALYs) were projected using Bayesian age–period–cohort models based on Global Burden of Disease 2023 data. CKD-attributable healthcare costs were estimated using nationally representative data from the China Health and Retirement Longitudinal Study and incorporated into a health-augmented macroeconomic model to estimate national and provincial gross domestic product (GDP) losses.

Results.

Age-standardized incidence and mortality rates are projected to remain relatively stable, while prevalence increases substantially. In contrast, age-standardized DALY rates are projected to decline, primarily driven by substantial reductions in YLLs despite increasing YLDs. The estimated cumulative per capita loss attributable to CKD during 2025–2060 was INT \$5,594 (95% CI, INT \$4,629–\$6,393). The cumulative GDP loss attributable to CKD from 2025 to 2060 is projected to be INT \$6.45 trillion (95% CI, INT \$5.34–\$7.37 trillion), equivalent to 0.40% (95% CI, 0.33%–0.46%) of total GDP during the same period. Substantial geographic heterogeneity was observed, with the largest GDP losses attributable to CKD in provinces of Hebei, Guangdong, and Henan, while the highest per capita GDP losses were projected in provinces of Qinghai, Hebei, and Jiangxi.

Conclusions.

CKD is projected to impose a rapidly growing clinical and economic burden across China over the next three decades. The substantial regional heterogeneity identified in this study highlights the need for province-specific strategies to strengthen CKD screening, early detection, long-term disease management, and healthcare resource planning. These findings provide evidence to support more effective allocation of kidney care resources and inform national strategies to mitigate the future burden of CKD.

Introduction

Chronic kidney disease (CKD) is a major and growing global public health challenge, affecting approximately 10% of the world's population[1]. According to the Global Burden of Disease Study 2023 (GBD 2023), CKD has risen from the 16th leading cause of death in 1990 to the 9th in 2023, with an age-standardized mortality rate of 17.2 per 100,000 population[2]. This upward trend likely reflects population aging and the increasing prevalence of metabolic risk factors, including diabetes, hypertension, and obesity[3].

In China, CKD also represents a pressing public health concern. More than 80 million individuals are currently estimated to be living with CKD, with an overall prevalence exceeding 8%[4]. Despite this high burden, CKD remains substantially underdiagnosed, and treatment costs are considerable[5, 6]. CKD frequently coexists with other chronic conditions, particularly hypertension and diabetes[7–10], and the risk of disease progression increases with age[11]. Without timely detection and effective management, many patients progress to end-stage kidney disease, requiring dialysis or transplantation, with profound implications for both individuals and health systems[12].

Beyond its clinical burden, CKD has far-reaching economic consequences. At the household level, long-term management—including repeated outpatient visits, medications, and hospitalizations—can generate substantial out-of-pocket expenditures and financial strain[13]. At the macroeconomic level, CKD can reduce effective labor supply through premature mortality and morbidity-related productivity losses, while also diverting household savings from investment toward healthcare consumption[14, 15]. These dynamics suggest that CKD is not only a challenge to the health system but also a threat to long-term economic growth.

However, existing data on the epidemiological and macroeconomic burden of CKD in China remain limited and fragmented. Most studies have focused on estimates of CKD prevalence, mortality, or direct medical costs[16, 17] retrospectively from cross-sectional data, while projection studies have largely examined epidemiological trends only. Although a growing body of international research has quantified the macroeconomic burden of non-communicable diseases[18, 19], few studies globally have integrated epidemiological projections with healthcare cost estimation and macroeconomic modeling for CKD specifically. Moreover, national-level estimates may obscure substantial geographical heterogeneity. China's provinces differ markedly in demographic structure, economic development, healthcare capacity, and exposure to CKD risk factors, likely leading to heterogeneous disease burden and complicating policy planning at the regional level. Generating comprehensive evidence at both national and provincial levels is therefore essential for informing resource allocation, priority setting, and targeted CKD prevention and management strategies across regions with differing demographic, epidemiological, and economic profiles.

To address these gaps, this study provides an integrated assessment of the future health and macroeconomic burden of CKD in mainland China and its 31 provinces from 2025 to 2060. We combine epidemiological projections based on GBD 2023 data, healthcare cost estimation using individual-level

data from the China Health and Retirement Longitudinal Study (CHARLS), and a decision-analytic macroeconomic model to quantify the impact of CKD on gross domestic product (GDP). By jointly examining epidemiological trends, healthcare expenditures, and macroeconomic outcomes at both national and provincial levels, this study aims to provide comprehensive evidence to inform regionally tailored CKD prevention and control strategies for an aging population in China.

Methods

Study design and overview

We conducted a modeling study to estimate the future epidemiological and macroeconomic burden of CKD in mainland China and its 31 provinces from 2025 to 2060. The analysis integrated three components: epidemiological projections of CKD burden, estimation of healthcare costs attributable to CKD, and macroeconomic modeling of the resulting impact on labor supply, capital accumulation, and gross domestic product (GDP). By combining these components within a unified analytical framework, we aimed to provide a comprehensive assessment of both the health and economic consequences of CKD at national and provincial levels.

Data sources

Age- and sex-specific estimates of CKD incidence, prevalence, mortality, years lived with disability (YLDs), years of life lost (YLLs), and disability-adjusted life years (DALYs) were obtained from the Global Burden of Disease Study 2023 (GBD 2023), which synthesized data from multiple sources including censuses, surveillance systems, hospital records, epidemiological studies, and population-based surveys[20, 21]. These data were available annually from 1990 to 2023 and served as the basis for our long-term projections.

To capture provincial heterogeneity, we obtained provincial-level CKD prevalence data from the Chinese Center for Disease Control and Prevention (China CDC) and used these estimates to disaggregate national GBD estimates across the 31 provinces of mainland China. Healthcare cost estimates were derived from the China Health and Retirement Longitudinal Study (CHARLS), a nationally representative longitudinal survey of adults aged 45 years and older. We used data from four waves conducted in 2011, 2013, 2015, and 2018, comprising approximately 17,000 individuals from 150 counties and 450 communities[22]. The CHARLS study received ethical approval from Peking University, and all participants provided informed consent. This study used de-identified secondary data and did not require additional ethical approval.

Population data for historical periods were obtained from the United Nations World Population Prospects[23], and forward projections from 2018 to 2060 were based on the Institute for Health Metrics and Evaluation (IHME) population forecasts[24].

Epidemiological projections

These demographic inputs were used to generate age- and sex-specific population denominators for epidemiological projections. We projected CKD incidence, prevalence, mortality, YLLs, YLDs, and DALYs from 2025 to 2060 using a Bayesian age–period–cohort (BAPC) model. This modeling framework accounts for age effects, temporal trends, and cohort-specific influences, allowing for flexible modeling of non-linear changes in disease burden over time[25]. The population was stratified into 20 five-year age groups ranging from 0–4 years to 90–94 years, with an open-ended category for individuals aged 95 years and older, and all analyses were conducted separately by sex.

Projected population counts were incorporated into the model to derive future case numbers and rates. Age-standardized estimates were calculated using the World Health Organization’s World Standard Population to facilitate comparisons in a population with changing demographic distributions over time [26]. All analyses were conducted in R (version 4.2.3) using the BAPC and INLA packages. Model convergence was assessed using posterior diagnostics, with additional details provided in the Supplementary Material.

Estimation of healthcare costs attributable to CKD

To estimate healthcare costs attributable to CKD, we first modeled the probability of CKD at the individual level using a probit regression based on CHARLS data, following a similar approach used in prior studies[27, 28]. Our analysis included individuals aged 50 years and above. Covariates included age, sex, educational attainment, marital status, rural versus urban residence, comorbid conditions (including hypertension, diabetes, and dyslipidemia), and behavioral factors such as smoking, alcohol use, and sleep duration. The predicted probability of CKD was then used as the primary explanatory variable in cost models.

We estimated the incremental healthcare costs associated with CKD using multivariable regression models, in which healthcare expenditures were specified as dependent variables and the predicted probability of CKD was included as the main independent variable. These models additionally adjusted for sociodemographic characteristics, comorbidities, household composition, and annual per capita household consumption. The coefficient of the CKD probability was interpreted as the incremental healthcare costs attributable to CKD.

The regression model used was:

$$cost_{iy} = \alpha + \beta_1 P(CKD)_{iy} + \beta_2 X_{iy} + u_{iy}$$

where $cost_{iy}$ denotes healthcare costs for individual i in year y (2015–2018).

Healthcare costs attributable to CKD were estimated separately for three categories of healthcare expenditures: outpatient costs, hospitalization costs, and out-of-pocket (OOP) payments, by applying the

CKD probability model to three separate expenditure regression models based on self-reported healthcare utilization. Outpatient and hospitalization costs represent spending associated with outpatient visits and inpatient admissions, respectively, whereas OOP payments refer to the portion of healthcare spending paid directly by patients after any insurance reimbursement. All costs in different survey waves were adjusted to 2023 values using the healthcare component of the Consumer Price Index in China[29] and converted into 2023 international dollars using purchasing power parity to facilitate comparison with international studies.

Macroeconomic modeling

We developed a decision-analytic macroeconomic model to estimate the impact of CKD on economic output at both national and provincial levels (see **eAppendix 1** for details). The model captures two principal pathways through which CKD affects the economy: reductions in effective labor supply due to excess mortality and morbidity-related productivity losses, and reductions in capital accumulation resulting from healthcare expenditures that displace household savings and investment[30, 31].

Our approach for projecting the macroeconomic burden of CKD in China is similar to those used by Bloom et al.[32] and Chen et al.[33]. To quantify the macroeconomic burden, we compared the projected GDP between two scenarios: a *baseline* scenario incorporating projected CKD epidemiological trends, and a *counterfactual* scenario assuming the absence of CKD in the population. The difference between these scenarios represents the economic burden attributable to CKD. To account for regional heterogeneity, the model was parameterized separately for each of the 31 provinces using province-specific demographic and economic parameters. Further details regarding the parameter selection and values are provided in **eTable 1** in **eAppendix 2**, and additional details in **eAppendix 3**.

Uncertainty and sensitivity analyses

Uncertainty in model inputs and parameters was propagated through the analysis using 2,000 bootstrap simulations, in which healthcare costs attributable to CKD were repeatedly resampled from their estimated distributions to generate uncertainty intervals for the economic burden estimates, and all estimates are presented with 95% uncertainty intervals. A 2% discount rate was used in the base-case analysis[34]. Sensitivity analyses were conducted using alternative discount rates of 0%, 2%, and 3% to evaluate the robustness of macroeconomic projections.

Results

Projection of Epidemiological Trajectory

Table 1 presents projected age-standardized CKD-related indicators for males and females in China from 2025 to 2060. Overall, age-standardized incidence and mortality of CKD are projected to remain relatively stable through 2060, whereas age-standardized prevalence rises sharply. Age-standardized incidence is

projected to decrease from 150.8 per 100,000 (95% CI, 142.3–159.3) in 2025 to 149.6 per 100,000 (95% CI, 0.0–373.1) in 2060 in females, and increase from 142.8 per 100,000 (95% CI, 134.1–151.6) to 157.0 per 100,000 (95% CI, 0.0–393.0) in males over the same period. The age-standardized mortality is projected to increase from 7.5 per 100,000 population in 2025 (95% CI, 6.5–8.6) to 8.2 per 100,000 in 2060 (95% CI, 0.0–54.2) in males, and from 6.2 per 100,000 (95% CI, 5.4–6.9) to 8.9 per 100,000 (95% CI, 0.0–47.3) in females over the same period. Age-standardized prevalence is projected to rise in both sexes, exceeding 15,000 per 100,000 by 2060. The total number of individuals living with CKD is projected to increase from 119 million (95% CI, 113–125) in 2025 to 217 million (95% CI, 0–508) in 2060 (**eTable 2**). Despite rising prevalence, age-standardized DALY rates are projected to decline gradually, driven by reductions in YLLs and improved survival. Further detailed results stratified by sex are provided in **eFigures 1–2** of **eAppendix 4**.

Table 1
Projected sex-specific trends and percentage changes in chronic kidney disease burden in China, 2025–2060

Prevalence (per 100,000)	2025 (95% CI)	2040 (95% CI)	2060 (95% CI)	Difference 2025–2060	Percentage change (%)
Overall	8301.2 (7901.0- 8701.5)	12000.2 (6543.8- 17456.5)	18814.0 (0.0- 44089.4)	10512.8	126.6
Female	8629.5 (8186.6- 9072.3)	12503.7 (6832.5- 18175.0)	19912.5 (0.0- 46519.8)	11283.0	130.8
Male	7730.4 (7282.4- 8178.4)	10572.8 (4960.5- 16185.0)	15940.6 (0.0- 40755.4)	8210.2	106.2
Incidence (per 100,000)					
Overall	148.7 (141.2- 156.2)	152.1 (79.5- 224.8)	163.9 (0.0- 397.1)	15.2	10.2
Female	150.8 (142.3- 159.3)	147.3 (73.3- 221.4)	149.6 (0.0- 373.1)	-1.2	-0.8
Male	142.8 (134.1- 151.6)	145.6 (71.2– 220.0)	157.0 (0.0- 393.0)	14.2	9.9
Death (per 100,000)					
Overall	6.9 (6.1–7.7)	8.6 (0.0-20.8)	9.2 (0.0– 49.0)	2.3	33.0
Female	6.2 (5.4–6.9)	7.9 (0.0-19.3)	8.9 (0.0-47.3)	2.7	43.6
Male	7.5 (6.5–8.6)	8.6 (0.0-24.3)	8.2 (0.0-54.2)	0.7	9.3
DALYs (years)					
Overall	244.2 (223.2- 265.3)	265.1 (11.1- 519.2)	236.5 (0.0- 920.2)	-7.7	-3.2
Female	217.6 (198.4- 236.7)	231.9 (11.0- 452.8)	205.7 (0.0- 795.5)	-11.9	-5.5

Prevalence (per 100,000)	2025 (95% CI)	2040 (95% CI)	2060 (95% CI)	Difference 2025–2060	Percentage change (%)
Male	266.0 (240.8– 291.2)	284.7 (0.0– 583.7)	246.5 (0.0– 1026.2)	-19.5	-7.4
YLLs (years)					
Overall	83.5 (78.5– 88.5)	72.2 (24.4– 120.1)	58.7 (0.0– 175.9)	-24.8	-29.7
Female	78.4 (72.9– 83.9)	67.3 (9.8– 124.8)	54.8 (0.0– 196.6)	-23.6	-30.1
Male	87.1 (81.7– 92.5)	73.8 (30.7– 117.0)	58.6 (0.0– 160.6)	-28.5	-32.8
YLDs (years)					
Overall	156.3 (138.9– 173.6)	184.1 (0.0– 425.9)	185.1 (0.0– 921.5)	28.8	18.4
Female	134.7 (119.4– 150.1)	155.3 (0.0– 353.8)	154.8 (0.0– 750.6)	20.1	14.9
Male	174.8 (153.4– 196.1)	204.1 (0.0– 514.9)	199.7 (0.0– 1125.6)	24.9	14.3

National Projection of Economic Burden Attributable to CKD

Table 2 presents estimated annual per capita healthcare costs attributable to CKD in China, with detailed estimates provided in **eTable 3** of **eAppendix 5**. The annual per capita healthcare cost attributable to CKD was estimated at INT \$9,771 (95% CI, INT \$1,840–17,703). Outpatient care accounted for the largest share, at INT \$7,102 per person (95% CI, INT \$763–13,439), followed by hospitalization costs at INT \$2,992 per person (95% CI, INT \$206–5,778) and OOP payments at INT \$1,139 per person (95% CI, INT \$192–2,087).

Table 2
Annual per-person costs attributable to chronic kidney disease in China, 2023
INT\$

Spending type	Annual CKD-attributable cost per person, 2023 INT\$		
	Estimate	95% confidence interval	
Total cost	9771	1840	17703
Outpatient care cost	7102	763	13439
Hospitalization cost	2992	206	5778
Out-of-pocket	1139	192	2087

Figure 1 shows the projected annual discounted GDP losses attributable to CKD from 2025 to 2060 under discount rates of 0%, 2%, and 3%, with 95% uncertainty intervals. **eFigure 3** presents CKD-attributable economic losses as a percentage of GDP, and **eFigure 4** shows projected per capita GDP losses. Under the base-case 2% discount rate, cumulative GDP losses attributable to CKD from 2025 to 2060 are projected to reach INT \$6.45 trillion in 2023 international dollars (95% CI, INT \$5.34–7.37 trillion; **eTable 4**). This corresponds to 0.40% of cumulative GDP over the projection period (0.33–0.46) and a cumulative per capita loss of INT \$5,594 (INT \$4,629–\$6,393). Cumulative human capital losses are estimated at 215 million person–years. Estimates were sensitive to the choice of discount rate: cumulative GDP losses increased to INT \$10.18 trillion (INT \$8.07–12.04 trillion) without discounting and decreased to INT \$5.20 trillion (INT \$4.38–5.86 trillion) under a 3% discount rate (**eTables 5–6**).

Provincial Projection of Economic Burden Attributable to CKD

Table 3 illustrates the projected geographic distribution of CKD-attributable GDP losses across provinces under the base-case 2% discount rate. In 2025, projected national GDP losses attributable to CKD were estimated at INT \$1072.39 million, with the largest losses concentrated in economically developed provinces, including Guangdong (INT \$113.82 million), Jiangsu (INT \$109.46 million), and Shandong (INT \$78.73 million) (**eTable 7**). Over the full projection period of 2025–2060, however, the distribution of macroeconomic burden shifted toward several central provinces with large populations and substantial CKD burden (Table 3). Hebei Province was projected to experience the greatest cumulative GDP loss (INT \$500.46 billion; 95% CI, INT \$452.99–542.67 billion), followed by Guangdong (INT \$434.35 billion; 95% CI, INT \$393.26–468.91 billion) and Henan (INT \$399.63 billion; 95% CI, INT \$364.68–430.94 billion). These provinces also had some of the largest projected CKD populations (**eTable 8** and **eFigure 5**). Corresponding provincial estimates under alternative discount rates of 0% and 3% are provided in **eTables 9–10**.

Table 3

Projected economic burden of chronic kidney disease across provinces in mainland China, 2025–2060, using a 2% discount rate

Province	Cumulative economic loss, million 2023 INT\$ (95% CI)	Percentage of total GDP in 2025–2060 (95% CI)	Per capita loss (95% CI)
Shanghai Municipality	87864.63 (76274.21–98214.91)	0.252 (0.218–0.282)	3518.83 (3054.65–3933.34)
Yunnan Province	185672.58 (169469.92–200279.02)	0.909 (0.831–0.982)	3917.39 (3575.53–4225.55)
Inner Mongolia Autonomous Region	119524.80 (108294.13–128976.14)	0.702 (0.636–0.757)	4950.33 (4485.19–5341.77)
Beijing Municipality	62169.28 (53789.93–69692.94)	0.192 (0.166–0.216)	2828.42 (2447.20–3170.72)
Jilin Province	132975.29 (120460.01–144149.60)	1.431 (1.296–1.551)	5501.84 (4984.03–5964.18)
Sichuan Province	358035.51 (326848.38–385616.81)	0.855 (0.781–0.921)	4261.94 (3890.69–4590.25)
Tianjin Municipality	49956.69 (44819.95–54378.68)	0.429 (0.384–0.467)	3588.54 (3219.56–3906.19)
Ningxia Hui Autonomous Region	27326.15 (24956.68–29401.90)	0.767 (0.701–0.825)	3778.87 (3451.19–4065.92)
Anhui Province	324824.63 (295458.99–349691.60)	0.991 (0.902–1.067)	5301.54 (4822.25–5707.39)
Shandong Province	258003.37 (233852.70–277874.52)	0.404 (0.366–0.435)	2531.15 (2294.22–2726.09)
Shanxi Province	105966.24 (96947.67–113735.62)	0.643 (0.588–0.689)	3022.90 (2765.62–3244.54)
Guangdong Province	434348.47 (393262.95–468910.87)	0.474 (0.429–0.512)	3433.21 (3108.46–3706.40)
Guangxi Zhuang Autonomous Region	283903.59 (257381.40–307560.57)	1.531 (1.388–1.659)	5641.26 (5114.26–6111.34)

Province	Cumulative economic loss, million 2023 INT\$ (95% CI)	Percentage of total GDP in 2025–2060 (95% CI)	Per capita loss (95% CI)
Xinjiang Uygur Autonomous Region	99263.84 (90646.87–106798.51)	0.747 (0.683–0.804)	3824.43 (3492.44–4114.72)
Jiangsu Province	212359.82 (186342.83–234680.89)	0.240 (0.211–0.265)	2495.85 (2190.08–2758.19)
Jiangxi Province	277456.49 (252363.79–299602.05)	1.254 (1.140–1.353)	6115.63 (5562.55–6603.76)
Hebei Province	500461.19 (452994.72–542666.83)	1.626 (1.473–1.764)	6681.10 (6047.43–7244.53)
Henan Province	399630.82 (364680.69–430940.12)	0.971 (0.886–1.048)	4005.89 (3655.55–4319.73)
Zhejiang Province	276194.40 (247534.50–300918.76)	0.473 (0.424–0.516)	4260.65 (3818.53–4642.06)
Hainan Province	38933.92 (35550.37–41900.71)	0.758 (0.692–0.815)	3846.72 (3512.42–4139.83)
Hubei Province	267244.55 (241731.94–288515.17)	0.688 (0.622–0.743)	4609.07 (4169.06–4975.92)
Hunan Province	357567.58 (325425.55–385212.61)	1.038 (0.945–1.118)	5360.09 (4878.27–5774.50)
Gansu Province	95869.94 (87050.15–103758.14)	1.139 (1.035–1.233)	3816.58 (3465.46–4130.60)
Fujian Province	119579.25 (106635.13–130524.94)	0.320 (0.285–0.349)	2867.24 (2556.87–3129.69)
Tibet Autonomous Region	14219.77 (12979.52–15313.02)	0.795 (0.726–0.855)	3882.41 (3543.78–4180.91)
Guizhou Province	228891.39 (207227.17–248003.32)	1.561 (1.413–1.690)	5912.13 (5352.56–6405.78)
Liaoning Province	205401.64 (187205.25–221380.59)	0.973 (0.887–1.049)	4803.49 (4377.96–5177.19)

Province	Cumulative economic loss, million 2023 INT\$ (95% CI)	Percentage of total GDP in 2025–2060 (95% CI)	Per capita loss (95% CI)
Chongqing Municipality	176609.12 (159466.91–190897.86)	0.848 (0.766–0.916)	5487.88 (4955.21–5931.88)
Shaanxi Province	175932.12 (159996.84–189128.43)	0.765 (0.696–0.822)	4433.08 (4031.54–4765.59)
Qinghai Province	48320.97 (43746.93–52450.08)	1.890 (1.711–2.051)	8124.55 (7355.49–8818.82)
Heilongjiang Province	157460.37 (142581.85–171377.56)	1.476 (1.337–1.607)	4924.21 (4458.92–5359.44)

Substantial heterogeneity in the economic burden was also observed across provinces (**eAppendix 6**). Although Hebei, Guangdong, and Henan experienced the largest GDP losses, smaller and less economically developed provinces were projected to bear a greater per capita burden. Per capita economic losses attributable to CKD were highest in Qinghai, at INT \$8,124.55 (95% CI, INT \$7,355.49–8,818.82), followed by Hebei at INT \$6,681.10 (95% CI, INT \$6,047.43–7,244.53), and Jiangxi at INT \$6,115.63 (95% CI, INT \$5,562.55–6,603.76). Similarly, Qinghai was projected to experience the largest economic loss relative to provincial GDP, at 1.89% (95% CI, 1.71–2.05%), followed by Hebei at 1.63% (95% CI 1.47–1.76%) and Guizhou at 1.56% (95% CI 1.41–1.69%). Provincial treatment costs attributable to CKD were highest in Guangdong, Hebei, and Henan in **eFigure 6**.

Discussion

Our projections suggest that CKD will remain a major and increasingly important public health and economic challenge in China through 2060. Although age-standardized DALY rates are projected to decline modestly over time, the absolute number of individuals living with CKD is expected to rise substantially, driven primarily by rapid population aging and the growing older population. Consequently, the demand for long-term CKD-related monitoring, outpatient care, and disease management is likely to increase considerably over the coming decades. By 2060, we project that about 217 million individuals in China will be living with CKD, accompanied by substantial increases in CKD-related deaths, DALYs, healthcare expenditures, and macroeconomic losses.

Our findings are broadly consistent with prior national and global studies documenting the rising burden of CKD. Bikbov et al. predicted that both the age-standardized mortality rate and age-standardized prevalence rate attributable to CKD would rise globally in the future[35]. Notably, increasing life expectancy, population aging, and the growing prevalence of metabolic risk factors—including hypertension, diabetes, and obesity—are contributing to sustained increases in CKD prevalence[36]. Similarly, Qi et al. reported that the global prevalence, and mortality of CKD increased steadily from 1990

to 2021 and would continue to rise through 2050[37]. Tan et al. found significant gender differences in CKD, with men exhibiting higher age-standardized DALYs[38]. Consistent with these trends, we observed relatively stable age-standardized incidence and mortality rates alongside substantial growth in the absolute number of CKD cases. This apparent divergence reflects demographic changes rather than worsening disease risk at the population level. Importantly, we also projected gradual declines in age-standardized DALY rates, suggesting that improvements in survival, earlier detection, and advances in CKD management may partially offset increases in disease burden. Nevertheless, these gains are unlikely to fully counterbalance the large increase in total CKD cases associated with population aging.

At the national level, our estimates of CKD prevalence in China are in line with prior projections. Li et al. found that, from 1990 to 2019, the prevalence and mortality rates of CKD in China increased significantly from 6.7% and 8.3 per 100,000 person-years to 10.6% and 13.8 per 100,000 person-years, respectively. Moreover, they predicted that the prevalence and mortality rates of CKD per 100,000 population would increase to 11.7% and 17.1%, respectively, by 2029[39]. Jian et al. estimated that from 2020 to 2025, the number of CKD patients in China would rise from 153 million to 165 million, accounting for more than 10% of the total population[6].

We also observed important sex differences in projected CKD burden. Females were projected to experience higher prevalence and mortality, whereas males had consistently higher incidence and DALYs. These findings are consistent with earlier studies suggesting that biological, behavioral, and healthcare-related factors may contribute differently to CKD risk and progression across sexes[40]. Higher incidence and DALY burden among males may partly reflect greater exposure to behavioral risk factors such as smoking and alcohol use, as well as lower healthcare utilization and delayed disease detection. These findings underscore the importance of incorporating sex-sensitive approaches into CKD prevention and management strategies[41].

Our analysis further suggests that CKD imposes a substantial economic burden at both household and societal levels. Estimated annual healthcare expenditures attributable to CKD were considerable, with outpatient care accounting for the largest share of costs. This pattern likely reflects the large proportion of individuals living with early- and middle-stage CKD who require ongoing outpatient monitoring, medication use, and chronic disease management rather than inpatient treatment alone[42]. Although China's regulated healthcare pricing system and expanding insurance coverage may help limit hospitalization and out-of-pocket expenditures relative to some high-income countries[43, 44], the projected economic burden remains substantial given the scale of the affected population. Continued expansion of accessible and affordable outpatient management may therefore play a critical role in reducing long-term complications and healthcare costs associated with CKD progression.

At the macroeconomic level, our findings indicate that CKD may exert sustained pressure on China's long-term economic development. Under the base-case analysis, cumulative GDP losses attributable to CKD are projected to approach \$6 trillion between 2025 and 2060, reflecting the combined effects of premature mortality, reduced labor-force participation, morbidity-related productivity losses, and

healthcare expenditures that displace savings and investment. Although the proportional GDP losses associated with CKD are smaller than those reported for some other major non-communicable diseases[34], the magnitude of projected losses remains substantial, particularly in the context of rapid population aging and slowing workforce growth in China. These findings suggest that CKD should be viewed not only as a clinical and public health issue, but also as a long-term economic development challenge.

A major contribution of this study is the identification of substantial geographic heterogeneity in the projected macroeconomic burden of CKD across China's provinces. Provinces such as Hebei, Guangdong, and Henan were projected to experience the largest macroeconomic losses, although the underlying drivers differed across regions. In provinces such as Hebei and Henan, high burden appeared to be driven primarily by elevated CKD prevalence combined with large population size[4]. In contrast, Guangdong's substantial losses were more strongly related to its large economic scale and workforce productivity. Meanwhile, several less-developed provinces, including Qinghai and Guizhou, were projected to experience disproportionately high per capita economic burden despite smaller GDP loss. These findings suggest that the future burden of CKD will not be evenly distributed across China and that national averages may obscure important regional vulnerabilities. Such provincial heterogeneity is increasingly recognized as a defining feature of NCD burden in large, demographically diverse countries: several studies[45–47] have similarly demonstrated that aggregate national estimates can mask substantial regional concentrations of burden and vulnerability, supporting the value of provincially resolved modeling for NCD economic burden assessment in comparable settings. Beyond China, these findings highlight the importance of integrating epidemiological projections, healthcare cost estimation, and macroeconomic modeling at provincial levels in other large and aging countries, where substantial regional variation in disease burden and healthcare resources may similarly influence the future economic consequences of chronic diseases.

The observed regional heterogeneity has important policy implications. Strategies focused solely on national-level burden reduction may fail to adequately address provinces facing particularly high per capita burden or being more resource-constrained. Our findings support the need for regionally tailored and equity-oriented CKD prevention strategies that account for differences in demographic structure, healthcare access, economic development, and underlying risk-factor distribution. For example, provinces with the largest GDP loss, such as Hebei and Guangdong, may benefit from expanding risk-based CKD screening programs[48], strengthening integrated chronic disease management, and improving coordination between primary care and specialist services to facilitate earlier diagnosis and slow disease progression[49], given their large affected populations and substantial healthcare demand. In contrast, provinces experiencing the highest per capita economic losses, such as Qinghai and Jiangxi, may require targeted investments in primary healthcare capacity, improved access to long-term CKD management and kidney replacement services, and strengthened financial protection mechanisms to mitigate disparities in healthcare access and outcomes. Consistent with recent evidence highlighting persistent regional inequalities in ESKD care in China, strengthening community-based care delivery, enhancing quality-monitoring systems, and advancing whole-course CKD management may help reduce

regional disparities in both health and economic outcomes[50]. Together, these measures could contribute to more equitable access to CKD prevention and care and help reduce future regional inequalities in both health and economic outcomes.

This study has several limitations. First, the analysis did not differentiate CKD by disease stage, despite substantial variation in healthcare costs, progression rates, and mortality across stages of disease severity. Second, our estimates did not include informal caregiving costs, productivity losses among unpaid caregivers, or broader social welfare impacts, which may lead to underestimation of the total societal burden of CKD. Third, cost estimates were derived from self-reported survey data and may therefore be subject to recall bias or underreporting. Furthermore, patients receiving long-term dialysis may have been underrepresented in CHARLS, potentially resulting in underestimation of CKD-related healthcare expenditures. Fourth, provincial population projections assumed constant provincial population shares over time and may not fully capture future migration-related population changes. Finally, our projections did not explicitly model the potential impact of future preventive interventions, healthcare reforms, or therapeutic innovations that could alter CKD incidence, progression, treatment regimen, survival, disease management cost over time.

Conclusion

In conclusion, CKD is projected to impose a substantial and increasingly uneven health and macroeconomic burden across China over the next three decades. Although improvements in survival and disease management may reduce CKD burden in terms of age-standardized DALYs, rapid population aging is expected to drive large increases in the absolute number of CKD cases, healthcare demand, and macroeconomic losses. Strengthening early detection, risk-factor control, and long-term CKD management—particularly through regionally tailored and equity-oriented strategies—will be essential to mitigate the growing impact of CKD and support healthy aging and sustainable economic development in China. Beyond China, these findings underscore the value of treating CKD not only as a clinical condition but as a long-term determinant of macroeconomic resilience in aging societies, and offer a methodological foundation that other large, demographically transitioning countries may draw on to inform their own NCD planning.

Abbreviations

BAPC

Bayesian age-period-cohort

CHARLS

China Health and Retirement Longitudinal Study

CKD

Chronic kidney disease

DALYs

Disability-adjusted life years

ESKD
End-stage kidney disease
GBD
Global Burden of Disease
GDP
Gross domestic product
IHME
Institute for Health Metrics and Evaluation
INLA
Integrated nested Laplace approximation
INT\$
International dollars
NCD
Non-communicable disease
OOP
Out-of-pocket
YLDs
Years lived with disability
YLLs
Years of life lost

Declarations

Ethics approval and consent to participate

The China Health and Retirement Longitudinal Study (CHARLS) was approved by the Ethics Review Committee of Peking University, and all participants provided informed consent. The present study used de-identified secondary data and did not involve direct recruitment of human participants; therefore, additional ethical approval and informed consent were not required.

Consent for publication

Not applicable.

Availability of data and materials

The Global Burden of Disease (GBD) 2023 data used in this study are publicly available through the Institute for Health Metrics and Evaluation (IHME) at <https://ghdx.healthdata.org/gbd-results-tool>. The China Health and Retirement Longitudinal Study (CHARLS) data are available upon approved application through the National School of Development, Peking University (<https://charls.charlsdata.com/>). Provincial-level CKD prevalence data were provided by the Chinese Center for Disease Control and Prevention (China CDC) under a data use agreement and are not publicly available.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

LZ and YL conceived and supervised the study. YS and XL performed the analyses and drafted the manuscript. PL, FW, QC, and LW contributed to data acquisition, methodology development, and interpretation of the results. All authors critically revised the manuscript. All authors reviewed and approved the final manuscript and agree to be accountable for all aspects of the work.

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Figures

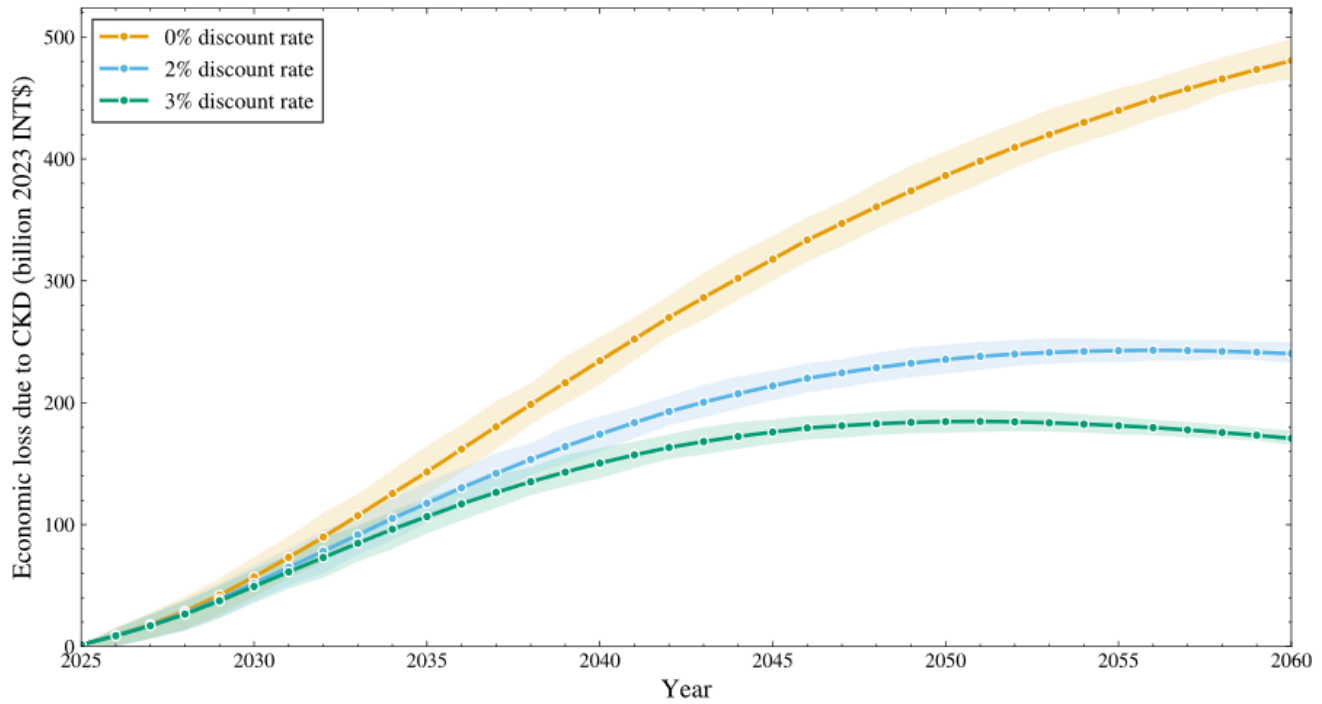


Figure 1

Projected economic burden of chronic kidney disease in China, 2025–2060, under alternative discount rates (0%, 2%, and 3%)

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