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Thirty-Year Global and Regional Evaluation of Epidemiological Changes in Chronic Kidney Disease

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Abstract

Chronic kidney disease (CKD) represents an increasing challenge for global health, with marked differences in its impact across various countries and regions. This research focused on evaluating the patterns in CKD incidence, prevalence, mortality, and disability-adjusted life years (DALYs) spanning the period from 1990 to 2019, based on data from the Global Burden of Disease Study. A thorough investigation was carried out to assess the global as well as age-standardized rates of CKD incidence, prevalence, mortality, and DALYs over three decades. The study also examined how healthcare access and quality (HAQ) and the Socio-Demographic Index (SDI) relate to CKD outcomes. Moreover, six key risk factors closely tied to CKD were analyzed in detail to support evidence-based recommendations for better CKD management. In 2019, the total number of CKD cases reached 18,986,903, with an average annual percent change (AAPC) in incidence of 1.82 (95 percent CI = 1.8 to 1.82) since 1990. The age-standardized incidence rate climbed from 192.45 per 100,000 in 1990 to 233.65 per 100,000 in 2019. Similarly, prevalence grew to 69,729,430 cases, accompanied by an AAPC of 1.19 (95 percent CI = 1.19 to 1.2). Corresponding rises were observed in mortality and DALYs, with mortality rates reaching 18.29 per 100,000 and total DALYs at 41,538,592 in 2019. The data revealed that regions with higher HAQ scores experienced better outcomes, indicated by lower mortality and DALYs, while lower HAQ scores were associated with adverse outcomes. High fasting plasma glucose and elevated systolic blood pressure emerged as the leading contributors to CKD-related deaths, and their population attributable fraction (PAF) declined substantially as SDI decreased. The global burden of CKD has markedly intensified over the past thirty years, influenced by demographic changes and disparities in healthcare quality and availability. Addressing these gaps through effective public health policies and improvements in healthcare delivery is crucial for reducing the uneven distribution of CKD outcomes worldwide.

Keywords: Prevalence, Epidemiology, Chronic kidney disease, Incidence, Global health

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Introduction

Chronic kidney disease (CKD) is identified either by evidence of kidney damage or by a sustained reduction in glomerular filtration rate (GFR) below 60 ml/min/1.73 m² lasting for at least three months [1]. According to GFR-based classification, CKD is divided into five stages: G1 (≥ 90 ml/min/1.73 m²), G2 (60–89 ml/min/1.73 m²), G3a (45–59 ml/min/1.73 m²), G3b (30–44 ml/min/1.73 m²), G4 (15–29 ml/min/1.73 m²), and G5 (< 15 ml/min/1.73 m²) [2]. This disease leads to gradual and irreversible deterioration of kidney structure and function over months to years [3–5]. CKD markedly raises the risk of early death, with mortality rates being 5 to 10 times greater than the chance of advancing to end-stage renal disease (ESRD). In 2017, CKD affected nearly 700 million individuals worldwide [6], exhibiting a prevalence higher than diabetes, osteoarthritis, and chronic obstructive pulmonary disease (COPD) [7]. That same year, CKD accounted for around 1.2 million deaths globally, exceeding fatalities caused by tuberculosis or HIV and nearing those from road traffic injuries [6]. Extensive studies have established diabetes and hypertension as primary contributors to CKD across all income brackets [8–11]. CKD involves progressive loss of nephron units, reduced kidney regenerative capacity, microvascular injury, metabolic disturbances, oxidative stress, and inflammation [5]. These processes collectively lead to fibrosis and further nephron depletion. The pathophysiology of CKD encompasses several mechanisms, including nephron loss, compensatory hypertrophy, impaired glomerular filtration, and tissue fibrosis. Additionally, numerous factors can trigger CKD onset, such as low birth weight, pregnancy-related complications, obesity, diabetes, and aging. These conditions not only initiate but also accelerate nephron loss, creating a self-perpetuating cycle of damage that ultimately results in ESRD [12].

Epidemiologic transition and population growth have greatly influenced the patterns of non-communicable diseases like diabetes and hypertension, thereby affecting the global burden of CKD [13]. However, detailed evaluations of the CKD burden at global, regional, and national scales over the past thirty years remain limited.

This study leverages data from the Global Burden of Disease (GBD) study covering 1990 to 2019 to thoroughly examine CKD incidence, prevalence, mortality, and disability-adjusted life years (DALYs) across worldwide, regional, and national contexts. We also assess how epidemiological shifts and demographic growth have shaped the CKD burden during this timeframe, while analyzing the associations between the Socio-Demographic Index (SDI) and the Healthcare Access and Quality (HAQ) index in various countries. Furthermore, by investigating exposure levels to risk factors and their related disease burdens, this research provides crucial evidence to guide the formulation and implementation of effective strategies and policies aimed at preventing and reducing the future rise of CKD.

Materials and Methods

Data sources

This analysis relies on information from GBD 2019, which compiles epidemiological data on 369 diseases covering 21 GBD regions and 204 countries and territories from 1990 through 2019 [14–16]. The 21 regions are grouped based on similarities in disease patterns and geographical proximity, and are further classified into five categories based on the Socio-Demographic Index (SDI): low, low-middle, middle, high-middle, and high SDI [15, 17]. We collected data on the number and rate (per 100,000 population) of incident and prevalent cases, mortality counts and rates (per 100,000 population), as well as counts and rates of disability-adjusted life years (DALYs) per 100,000 person-years, all stratified by sex, age group, geographic region, and country. Age standardization was performed according to the World Health Organization's global standard age distribution [13]. The methodology adheres strictly to the Guidelines for Accurate and Transparent Health Estimates Reporting (GATHER) [18].

Socio-demographic index (SDI)

The SDI is a composite metric reflecting development on a scale from 0 to 1, derived from three indicators: total fertility rate among women under 25 years (TFU25), average educational attainment for individuals aged 15 and above (EDU 15+), and lag-distributed income per capita (LDI). A score near zero corresponds to regions with the highest fertility rates and lowest education and income levels, whereas a score approaching one signifies the opposite conditions [19, 20].

Healthcare access and quality (HAQ) index

The HAQ index quantifies healthcare system performance on a scale from 0 to 100 by evaluating risk-standardized mortality rates for 32 GBD causes. This measure enables a comparative overview of healthcare access and quality across 195 countries and territories, accounting for temporal changes and developmental status [21].

Risk factors

Key contributors to chronic kidney disease (CKD) include elevated systolic blood pressure, raised fasting plasma glucose, increased body mass index (BMI), poor dietary habits, insufficient physical activity, and environmental hazards. The GBD study carefully selected these risk factors based on strong causal evidence, the presence of comprehensive exposure data, their modifiability through behavioral or other interventions, and their policy

relevance. For GBD 2019, only risk-outcome relationships meeting the World Cancer Research Fund's standards of convincing or probable evidence were included when compiling relative risk estimates. These relative risks were derived using an extensive and systematic approach [22, 23]. Exposure information was obtained from diverse, reliable sources: data on high systolic blood pressure were collected from published studies and detailed household survey microdata such as STEPS and NHANES; fasting plasma glucose levels were estimated using population mean values, individual-level survey data, and diabetes prevalence rates; adult BMI (20+ years) classifications considered BMI thresholds over 20–25 kg/m², with dietary risk data sourced through literature searches in PubMed and updates from the IHME Global Health Data Exchange; physical inactivity was assessed by recording physical activity lasting a minimum of 10 minutes across all domains in adults aged 25 and above; environmental risks, including radon and lead exposure, were evaluated using expert-compiled datasets, national surveys, governmental reports, and scientific literature [24]. The population attributable fraction (PAF) quantifies the proportion of CKD cases that could be prevented if exposure to a risk factor were eliminated. In GBD 2019, PAFs were calculated by combining the risk function, exposure distribution for each age, sex, location, and year subgroup, meta-analytically derived relative risks, and theoretical minimum risk exposure levels for each risk-outcome pair [25].

Statistical analysis

To evaluate temporal trends from 1990 to 2019, we utilized the age-standardized estimated annual percentage change (ASR-EAPC) to quantify changes over time intervals [26–29]. Using the Global Burden of Disease (GBD) dataset, age-standardized rates for incidence (ASIR), prevalence (ASPR), mortality (ASMR), and disability-adjusted life years (ASDR) related to CKD were calculated at global, regional, and national levels. Visual representation was provided through a world map. The EAPC metric was derived through fitting a linear regression model: $\ln(y) = \alpha + \beta x + \varepsilon$, where y refers to ASIR, ASPR, ASMR, or ASDR; α is the intercept; x denotes the calendar year; β is the slope coefficient; and ε is the normally distributed residual. The EAPC is then computed as EAPC= (exp^β-1)×100%, with corresponding 95% confidence intervals (CI). An EAPC estimate with a positive value and a lower CI above zero indicates a statistically significant upward trend, while an EAPC and upper CI below zero signify a declining trend in the age-standardized rate. In addition, rates were analyzed by sex and age group to capture patterns across different life stages.

We applied Joinpoint regression models to calculate average annual percent changes (AAPCs) on logarithmically transformed data [30–32]. Year was modeled as the independent variable, while incidence, prevalence, mortality, and DALYs rates served as dependent variables. AAPCs and 95% CIs represent the average yearly percent increase, decrease, or stability, with an example being an AAPC of 0.5 indicating a 0.5% annual rise. To explore the association between age-standardized rates and the Socio-Demographic Index (SDI), Pearson's correlation coefficient (R) was computed across various geographic levels [33]. Furthermore, to understand CKD burden in healthcare systems worldwide, relationships between ASIR, ASPR, ASMR, ASDR, and the Healthcare Access and Quality (HAQ) index were examined [13].

To dissect the contributions of population aging, epidemiological transitions, and demographic growth to the changes in CKD incidence, prevalence, mortality, and DALYs, the decomposition technique introduced by Das Gupta was utilized [13, 34–36]. The formula applied—for example, in the case of incidence—is outlined as follows:

$$Incidence_{ay,py,ey} = \sum_{i=1}^{20} \left(a_{i,y} \times p_y \times e_{i,y}\right) \quad (1)$$

ay, py, and ey represented the incidence levels attributable to population aging, population size, and age-specific incidence rates in a given year, respectively. Specifically, $a_{i,y}$ denoted the proportion of individuals within age group i among the 20 defined age groups during year y, p_y reflected the total population for that year, and $e_{i,y}$ indicated the incidence rate corresponding to age group i in year y. The relative influence of each component on the change in CKD incidence between 1990 and 2019 was calculated by isolating the effect of one variable at a time, holding the others constant. All data processing and statistical evaluations were carried out using R software (version 4.2.2, R Foundation, Vienna, Austria; https://www.r-project.org/) and the Joinpoint regression software (version 4.9.1.0, Surveillance Research Program, National Cancer Institute, USA). A two-sided P-value < 0.05 was considered statistically significant throughout the analysis.

CKD incidence trends

Globally, the number of new CKD cases increased substantially, rising from 7,796,328 cases (95% uncertainty interval [UI]: 7,174,529 to 8,485,391) in 1990 to 18,986,903 cases (95% UI: 17,556,535 to 20,518,156) by 2019. This reflects a steady global escalation in CKD incidence over the past 30 years, with an average annual percent change (AAPC) of 1.82% (95% confidence interval [CI]: 1.81 to 1.82) starting from 1990 **(Figure 2)**. In 2019, the age-standardized incidence rate (ASIR) was recorded at 233.65 per 100,000 population (95 percent UI: 216.56 to 252.31) **(Figure 1)**. Additionally, this rate

demonstrated a notable upward trend over time, with an estimated annual percent change (EAPC) of 0.69% (95% CI: 0.68 to 0.7) **(Figure 2)**. The incidence associated with major contributors—type 1 diabetes mellitus (T1DM), type 2 diabetes mellitus (T2DM), hypertension, glomerulonephritis, and other unspecified causes—also revealed rising patterns relative to the levels in 1990. Among these, the overall EAPC was estimated at 1.21% (95% CI: 1.08 to 1.34).

Table 1. Age-standardized rate for CKD incidence, prevalence, mortality and DALYs, and percentage change from 1990 globally and by SDI quintile

Location	Overall difference	Incidence changes due to population-level determinants*			Overall difference	Prevalence changes due to population-level determinants*		
		Aging	Epidemiologic changes	Population		Aging	Epidemiologic changes	Population
Global	11,190,575	4,062,899 (36.31%)	2,504,662 (22.38%)	4,623,015 (41.31%)	355,628,727	128,836,443 (36.23%)	43,839,120 (12.33%)	182,953,164 (51.44%)
High SDI	2,515,612	1,317,277 (52.36%)	409,355 (16.27%)	788,980 (31.36%)	52,220,767	27,475,062 (52.61%)	5,187,526 (9.93%)	19,558,179 (37.45%)
High-middle SDI	2,352,164	1,096,555 (46.62%)	643,558 (27.36%)	612,051 (26.02%)	70,047,763	36,028,864 (51.43%)	8,385,858 (11.97%)	25,633,042 (36.59%)
Middle SDI	3,919,423	1,629,060 (41.56%)	1,099,990 (28.07%)	1,190,373 (30.37%)	132,640,959	60,632,059 (45.71%)	17,215,583 (12.98%)	54,793,318 (41.31%)
Low-middle SDI	1,759,392	510,652 (29.02%)	459,582 (26.12%)	789,159 (44.85%)	71,544,023	24,433,408 (34.15%)	7,447,516 (10.41%)	39,663,100 (55.44%)
Low SDI	636,710	1027 (0.16%)	156,960 (24.65%)	478,723 (75.19%)	28,958,173	1,911,574 (6.60%)	2,886,189 (9.97%)	24,160,411 (83.43%)
Location	**Overall difference**	**Mortality changes due to population-level determinants***			**Overall difference**	**DALYs changes due to population-level determinants***		
		Aging	**Epidemiologic changes**	**Population**		**Aging**	**Epidemiologic changes**	**Population**
Global	825,925	374,932 (45.40%)	100,884 (12.21%)	350,109 (42.39%)	20,034,022	7,377,149 (36.82%)	1,534,475 (7.66%)	11,122,398 (55.52%)
High SDI	174,118	88,796 (51.00%)	49,042 (28.17%)	36,280 (20.84%)	2,836,831	1,295,203 (45.66%)	749,976 (26.44%)	791,652 (27.91%)
High-middle SDI	111,660	84,682 (75.84%)	-9344 (-8.37%)	36,322 (32.53%)	2,158,988	1,609,950 (74.57%)	-514,477 (-23.83%)	1,063,516 (49.26%)
Middle SDI	309,540	180,807 (58.41%)	19,314 (6.24%)	109,419 (35.35%)	7,884,029	4,096,712 (51.96%)	139,623 (1.77%)	3,647,694 (46.27%)
Low-middle SDI	166,977	75,344 (45.12%)	3811 (2.28%)	87,822 (52.60%)	4,863,576	1,733,526 (35.64%)	-51,140 (-1.05%)	3,181,191 (65.41%)
Low SDI	63,054	5331 (8.45%)	-10,756 (-17.06%)	68,479 (108.60%)	2,274,783	69,263 (3.04%)	-441,102 (-19.39%)	2,646,622 (116.35%)

DALYs – disability-adjusted life years, SDI – Socio-demographic Index

*Percentages contribute to the total changes

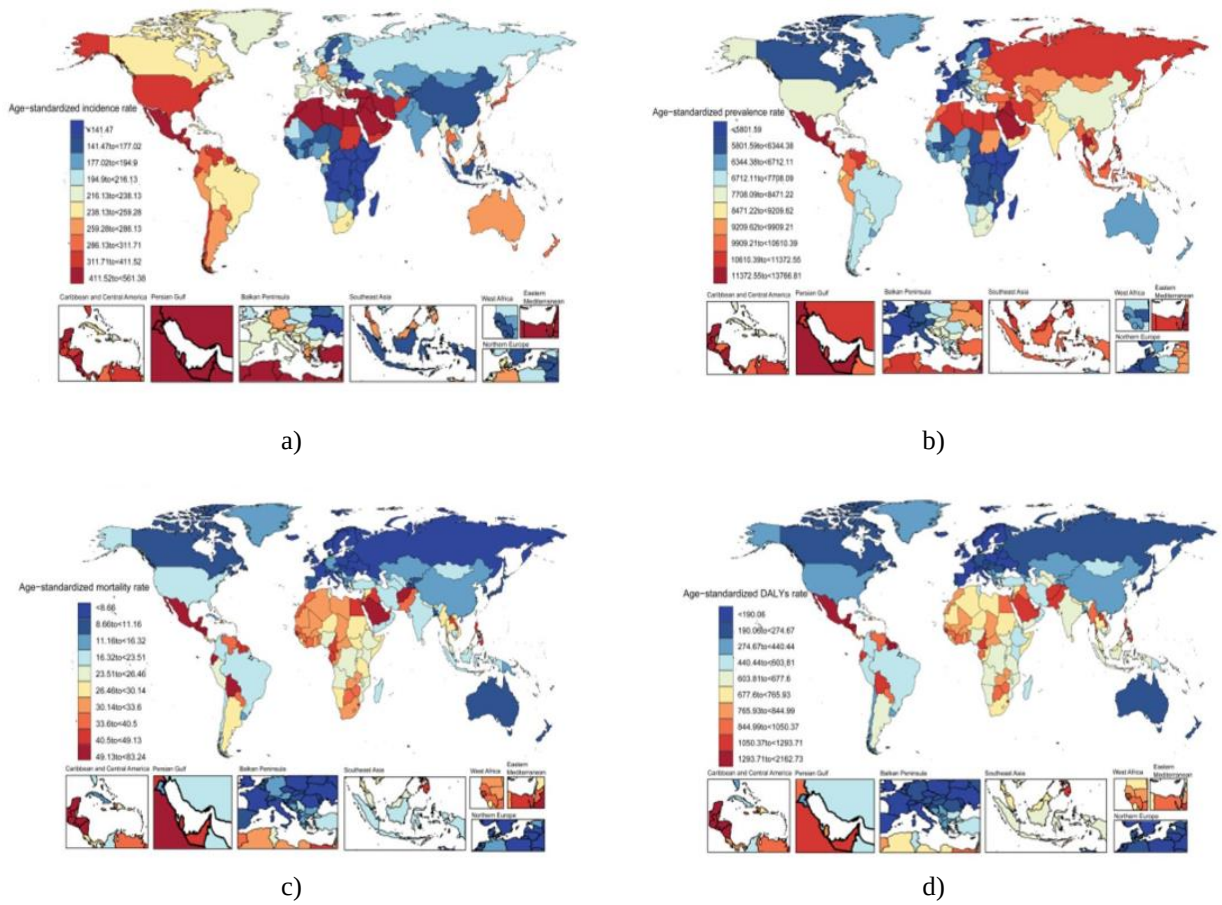


Figure 1. The geographic variation in the age-standardized incidence rate (a), age-standardized prevalence rate (b), age-standardized mortality rate (c), and age-standardized disability-adjusted life years rate (d) of CKD across 204 countries and territories.

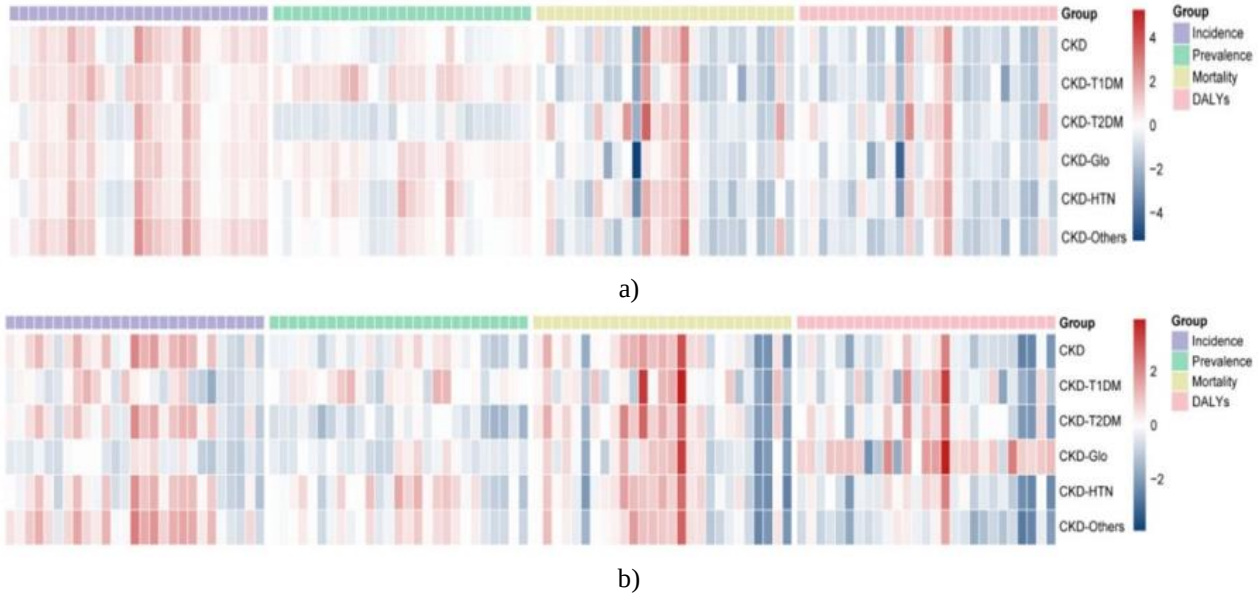


Figure 2. The estimated annual percentage change (a) along with the average annual percent change (AAPC) across the 21 GBD regions. These regions, listed from left to right, include: Global, High SDI, High-middle SDI, Middle SDI, Low-middle SDI, Low SDI, Central Asia, Central Europe, Eastern Europe, Australasia, High-income Asia Pacific, High-income North America, Western Europe, Andean Latin America, Caribbean, Central Latin America, Southern Latin America, Tropical Latin America, North Africa and Middle East, Southeast Asia, South Asia, East Asia, Oceania, Central Sub-Saharan Africa, Eastern Sub-Saharan Africa, Southern Sub-Saharan Africa, and Western Sub-Saharan Africa.

Based on the SDI quintiles, there was a progressive rise in incidence rates from low to high SDI regions. The most marked increase occurred in middle SDI regions (AAPC = 2.69; 95 percent CI = 2.68 to 2.7), while the least growth was observed in low SDI areas (AAPC = 1.87; 95 percent CI = 1.85 to 1.89). Among the 21 GBD regions, the highest age-standardized incidence rate (ASIR) per 100,000 for CKD was noted in North Africa and the Middle East (ASIR = 447.48; 95 percent UI = 415.13 to 482.83), followed by Central Latin America (ASIR = 409.61; 95 percent UI = 383.06 to 437.91), and High-income North America (ASIR = 310.44; 95 percent UI = 284.74 to 336.3) **(Figure 1)**. Over the last thirty years, Andean Latin America experienced the sharpest increase in incidence (AAPC = 3.56; 95 percent CI = 3.55 to 3.57), followed by Central Latin America (AAPC = 3.12; 95 percent CI = 3.11 to 3.13) and North Africa and Middle East (AAPC = 2.89; 95 percent CI = 2.87 to 2.9). A consistent upward trend in incidence was recorded across all regions (all AAPC > 0) **(Figure 2)**.

Out of 204 countries and territories, China (3,098,718; 95 percent UI = 2,812,225 to 3,412,879), India (2,161,590; 95 percent UI = 1,964,382 to 2,363,305), and the United States of America (1,724,082; 95 percent UI = 1,574,583 to 1,886,709) had the largest number of reported cases. Trend analysis revealed that Albania had the highest rate of increase (AAPC = 4.21; 95% CI = 4.14 to 4.27), followed by Bahrain (AAPC = 4.16; 95 percent CI = 4.12 to 4.20) and Bosnia and Herzegovina (AAPC = 4.15; 95 percent CI = 4.10 to 4.21). Notably, Afghanistan was the only country with a declining trend (AAPC = -0.24; 95 percent UI = -0.29 to -0.18), while incidence rates rose in all other nations. Saudi Arabia reported the highest ASIR (561.38 per 100,000 population; 95% UI = 524.55 to 598.58), followed by the United Arab Emirates (516.47 per 100,000 population; 95% UI = 476.76 to 558.41) and Qatar (506.35 per 100,000 population; 95% UI = 463.47 to 551.97). The most substantial increase in ASIR occurred in Morocco (EAPC = 2.65 percent; 95 percent CI = 2.57 to 2.72), Turkey (EAPC = 2.46 percent; 95 percent CI = 2.27 to 2.66), and Ecuador (EAPC = 2.37 percent; 95 percent CI = 2.24 to 2.49). Only six out of the 204 countries or regions experienced a slight decline in ASIR **(Figure 2)**. Overall, incidence rates have surged globally, with 23 countries showing an increase exceeding 300% since 1990. Among them, Qatar recorded the highest growth (1350.47%), followed by the United Arab Emirates (1219.43 percent) **(Figure 3)**.

The prevalence of CKD

Chronic kidney disease (CKD) has seen a marked global increase in prevalence, with an overall case growth of 104.09% compared to 1990, and a statistically significant average annual percent change (AAPC) of 1.19 (95 percent CI = 1.19 to 1.2). The age-standardized prevalence rate (ASPR) of CKD also demonstrated a steady rise over time (EAPC = 0.32 percent; 95 percent CI = 0.32 to 0.33), climbing from 7,855.83 per 100,000 people in 1990 to 8,596.21 per 100,000 in 2019 **(Figure 1)**.

Across all five primary etiologies of CKD, both prevalence and ASPR have increased. The highest ASPR was linked to CKD due to other and unspecified causes (6,342.15; 95 percent UI = 5,905.8 to 6,753.79), followed by CKD associated with type 2 diabetes mellitus (T2DM), which showed an ASPR of 1,576.35 (95% UI = 1,448.28 to 1,700.21).

In terms of socio-demographic index (SDI) categories, the middle SDI group recorded the highest case burden in 2019, with this region also leading in the growth of incidence and ASPR among the five SDI levels.

Among the 21 Global Burden of Disease (GBD) regions, East Asia reported the highest number of CKD cases (156,838,754; 95 percent UI = 144,507,123 to 169,062,378), whereas Central Latin America experienced the most rapid increase in incidence (AAPC = 2.2; 95 percent CI = 2.20 to 2.21). In 2019, this same region had the highest ASPR (12,139.27; 95 percent UI = 11,377.05 to 12,843.88). The region of North Africa and the Middle East exhibited the greatest ASPR growth over the three decades (EAPC = 1.17 percent; 95 percent CI = 1.13 to 1.22). Interestingly, only the High-income Asia Pacific region showed a decline in ASPR during this time **(Figure 2)**.

On a national scale, China (150,497,490; 95% UI = 138,612,025 to 162,338,825), India (115,223,088; 95% UI = 106,617,969 to 124,209,571), and the United States (40,241,611; 95% UI = 37,608,687 to 42,831,133) had the highest number of prevalent CKD cases in 2019. In contrast, Mauritius (13,766.81; 95% UI = 12,855.22 to 14,728.09), Mexico (13,418.53; 95% UI = 12,565.28 to 14,188.77), and Costa Rica (12,859.29; 95% UI = 12,284.46 to 13,498.62) had the highest ASPR values.

Countries with the steepest increases in prevalence from 1990 to 2019 included Tunisia (AAPC = 2.81; 95 percent CI = 2.81 to 2.82), Turkey (AAPC = 2.78; 95 percent CI = 2.76 to 2.79), and the Syrian Arab Republic (AAPC = 2.68; 95 percent CI = 2.65 to 2.71). Conversely, Afghanistan (AAPC = -0.3; 95 percent CI = -0.33 to -0.27) and Chad (AAPC = -0.16; 95 percent CI = -0.17 to -0.16) were the only two countries showing a downward trend in prevalence.

Regarding ASPR trends, the majority of countries reported increases, with Morocco experiencing the largest rise (EAPC = 1.52 percent; 95 percent CI = 1.5 to 1.54). However, six countries saw declines in ASPR, with the United Kingdom showing the sharpest drop (EAPC = -0.09%; 95 percent CI = -0.14 to -0.04).

Between 1990 and 2019, 27 countries experienced a rise in CKD prevalence exceeding 200 percent, with Qatar showing the most dramatic increase (845.71%). Notably,

Georgia was the only country to report a decrease in overall prevalence, with a reduction of -2.42% **(Figure 3)**.

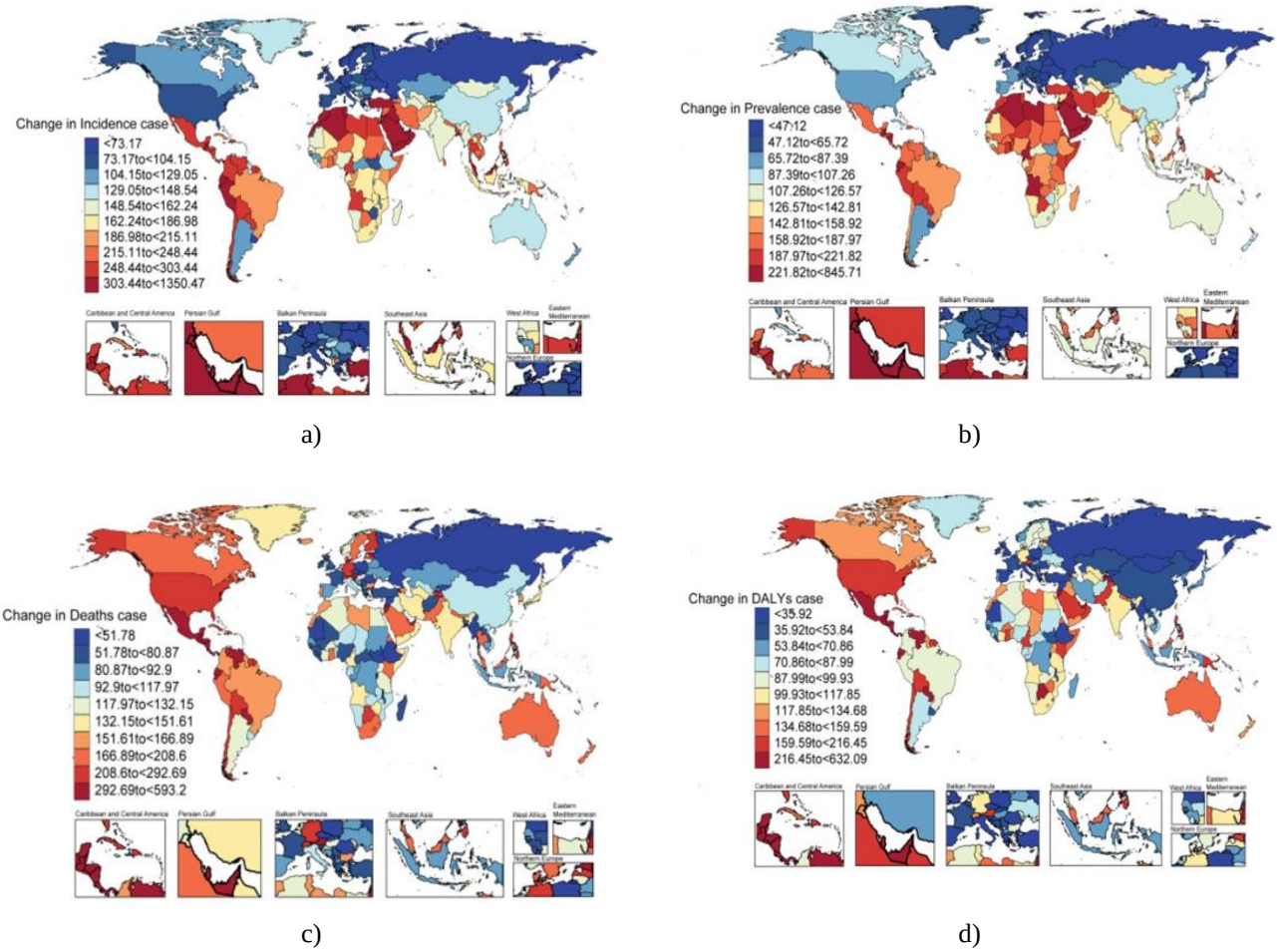


Figure 3. Geographic distribution illustrating the change in incidence cases (a), change in prevalence cases (b), change in deaths cases (c), and change in disability-adjusted life years cases (d) of CKD across 204 countries and territories.

Mortality of CKD

Over the past thirty years, the global mortality associated with CKD has steadily risen (AAPC = 1.75; 95 percent CI = 1.73 to 1.78), with deaths increasing from 601,307 in 1990 to 1,427,232 in 2019. The age-standardized mortality rate (ASMR) also showed a moderate rise, moving from 16.14 to 18.29 per 100,000 population during this time frame (EAPC = 0.55 percent; 95 percent CI = 0.46–0.64) **(Figure 2)**. In 2019, middle SDI regions recorded the highest death toll (506,130), while the highest ASMR was found in low SDI regions. Over the three decades, low SDI regions experienced declines in both mortality rate and ASMR (AAPC = -0.2; 95 percent CI = -0.22 to -0.19, EAPC = -0.27 percent; 95 percent CI = -0.31 to -0.22), whereas high-middle SDI regions maintained relatively stable levels. In contrast, high SDI regions showed a marked increase in these measures (AAPC = 2.8; 95 percent CI = 2.76 to 2.84, EAPC = 1.21 percent; 95 percent CI = 1.09 to 1.32).

Examining the five major causes of CKD, mortality rates and ASMR rose across all causes, with the largest surge linked to CKD caused by T2DM (AAPC = 2.21; 95 percent CI = 2.18 to 2.23, EAPC = 0.92 percent; 95 percent CI = 0.8 to 1.05) **(Figure 2)**.

Regionally, South Asia accounted for the highest number of deaths (285,342; 95 percent UI = 248,209 to 324,604), whereas Central Latin America had the highest ASMR (48.11 per 100,000 population; 95 percent UI = 42.52 to 54.16) **(Figure 1)**. Central Latin America also exhibited the steepest increases in mortality rate and ASMR (AAPC = 4.47; 95 percent CI = 4.32 to 4.56, EAPC = 1.44 percent; 95 percent CI = 1.31 to 1.58). Conversely, significant declines in mortality were seen in Eastern, Western, and Central Sub-Saharan Africa. ASMR trends declined in eight regions, with the greatest reductions observed in High-income Asia Pacific (EAPC = -1.35 percent; 95 percent CI = -1.43 to -1.28), Central Sub-Saharan Africa (EAPC = -0.64%; 95 percent CI = -0.68 to -0.61), and Eastern Sub-Saharan Africa (EAPC = -0.5 percent; 95 percent CI = -0.55 to -0.46) **(Figure 2)**.

Among the 204 countries and territories, the highest mortality counts were reported in India (222,922; 95 percent UI = 191,551 to 258,592), China (196,726; 95 percent UI = 168,241 to 224,684), and the United States of

America (2,287,706; 95%UI = 2,101,294 to 2,489,365). Noteworthy mortality trends were observed in Estonia, Armenia, and El Salvador. Mortality rates decreased in 39 countries, with Afghanistan showing the most significant drop (AAPC = -2.67; 95 percent CI = -2.72 to -2.61). The highest ASMR values were recorded in Nicaragua (83.24 per 100,000 population; 95 percent UI = 69.57 to 96.75), followed by Micronesia (Federated States of) and Mauritius. Estonia (EAPC = 5.36 percent; 95 percent CI = 4.91 to 5.81), Armenia (EAPC = 4.65 percent; 95 percent CI = 4.33 to 4.97), and Latvia (EAPC = 4.52 percent; 95 percent CI = 4 to 5.05) showed the most pronounced ASMR increases globally. Meanwhile, ASMR decreased in 78 countries, with Mongolia experiencing the largest reduction (EAPC = -3.6 percent; 95 percent CI = -4.07 to -3.12).

Between 1990 and 2019, deaths from CKD rose in nearly every country except Mongolia, which had a slight decrease (0.12%). The United Arab Emirates showed the greatest increase, with mortality rising by 593.20% **(Figure 3)**.

Disability-adjusted life years (DALYs) of CKD

In 2019, the total global DALYs attributed to CKD reached 41,538,592, reflecting an increase from 1990 levels. Over the thirty-year period, the DALYs rate steadily climbed with an average annual percent change (AAPC) of 1.02 (95% CI: 0.99 to 1.04). The age-standardized DALYs rate (ASDR) also rose from 484.46 per 100,000 in 1990 to 514.86 per 100,000 in 2019, showing a consistent upward trajectory (EAPC = 0.31 percent; 95 percent CI: 0.23 to 0.38) **(Figure 2)**. Among the five main CKD causes, CKD due to type 2 diabetes mellitus (T2DM) experienced the highest surge in DALYs rate (AAPC = 1.8; 95 percent CI: 1.77 to 1.82). The highest ASDR was reported for other and unspecified CKD causes (146.24; 95% UI: 123.41 to 172.09), while the sharpest increase in ASDR occurred in CKD linked to T2DM (EAPC = 0.75 percent; 95 percent CI: 0.63 to 0.87). In contrast, CKD caused by type 1 diabetes mellitus (T1DM) showed minimal change in ASDR (EAPC = -0.08 percent; 95 percent CI: -0.18 to 0.02).

Among socio-demographic index (SDI) regions, the middle SDI group bore the highest DALYs burden. Although the high SDI region had the second lowest DALYs count, it displayed the strongest upward trend (AAPC = 1.88; 95 percent CI: 1.86 to 1.9). The low SDI region had the highest ASDR, whereas the high SDI region reported the lowest; nonetheless, the high SDI group also showed the most significant rise in ASDR, paralleling its DALYs increase. The high-middle SDI region experienced the smallest reduction in ASDR (EAPC = -0.36 percent; 95 percent CI: -0.46 to -0.27), similar to the low SDI region's slight decline (EAPC = -0.24 percent; 95 percent CI: -0.28 to -0.21).

Analyzing the 21 Global Burden of Disease (GBD) regions, South Asia registered the greatest number of DALYs at 9,886,435 (95% UI: 8,796,773 to 11,052,833), while Central Latin America showed the highest ASDR at 1,348.14 (95% UI: 1,203.58 to 1,521.61) **(Figure 1)**. Central Latin America also experienced the most rapid DALYs rate growth (AAPC = 3.58; 95% CI: 3.51 to 3.64), though three regions saw DALYs rates decline. The steepest increase in ASDR was likewise observed in Central Latin America (EAPC = 2.3 percent; 95 percent CI: 2.01 **to 2.59), with thirteen regions** exhibiting declines in ASDR **(Figure 2)**.

Within 204 countries and territories, India held the highest DALYs count at 7,519,691 (95% UI: 6,550,348 to 8,500,578), followed by China with 5,831,843 (95% UI: 4,992,206 to 6,645,333) and the USA with 2,287,706 (95% UI: 2,101,294 to 2,489,365). The most pronounced increases in DALYs rate were seen in El Salvador (AAPC = 5.38; 95% CI: 5.08 to 5.62), Armenia (AAPC = 5.03; 95 percent CI: 4.86 to 5.2), and Estonia (AAPC = 4.66; 95 percent CI: 4.2 to 5.03). Meanwhile, 49 countries experienced declines in DALYs rates, with Ethiopia (AAPC = -2.36; 95% CI: -2.41 to -2.29), Afghanistan (AAPC = -2.1; 95 percent CI: -2.16 to -2.01), and Liberia (AAPC = -1.75; 95 percent CI: -1.84 to -1.68) showing the largest reductions.

Micronesia (Federated States of Micronesia) had the highest ASDR at 2,162.73 per 100,000 population (95% UI: 1,584.61 to 2,761.55), while Finland recorded the lowest at 111.94 per 100,000 (95% UI: 97.61 to 129.02) **(Figure 1)**. Out of 204 countries, 77 showed downward trends in ASDR, with Mongolia experiencing the greatest decline (EAPC = -3.33 percent; 95 percent CI: -3.76 to -2.9), while El Salvador had the largest increase (EAPC = 3.97 percent; 95 percent CI: 3.32 to 4.61) **(Figure 2)**.

Between 1990 and 2019, the fastest growth in DALYs was reported in the United Arab Emirates (632.10 percent) and Qatar (508.32 percent). Conversely, Slovakia experienced a slight decrease (0.22%), and Poland had a notable reduction (16.44%) in DALYs **(Figure 3)**.

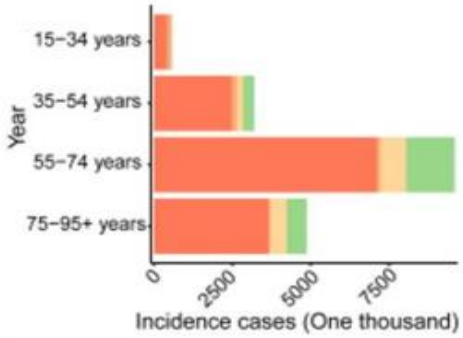
Age and gender-based snalysis of CKD

For a detailed examination of age-related differences in CKD, the population was split into four age brackets: 15–34, 35–54, 55–74, and 75–95+ years. The data revealed that individuals aged 55–74 accounted for the majority of CKD cases, both regarding new incidence and disability-adjusted life years (DALYs) **(Figures 4a and 4d)**. Mortality due to CKD mainly impacted those older than 55, with “other and unspecified” causes leading in incidence, followed by type 2 diabetes mellitus (T2DM). The prevalence distribution was similar to incidence

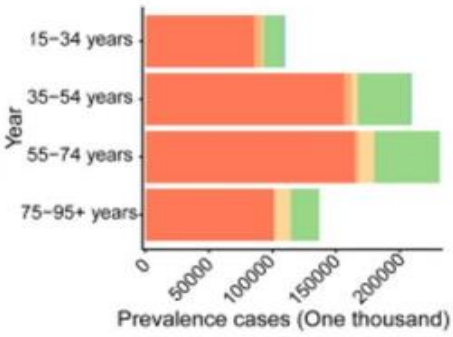
patterns, with type 1 diabetes mellitus (T1DM), hypertension, and glomerulonephritis making up a smaller proportion **(Figure 4b)**. Mortality causes did not differ significantly between the 15–34 and 35–54 age groups, but the influence of hypertension and T2DM increased substantially in the 55–74 and 75+ age ranges **(Figure 4c)**. Among younger groups (15–34 and 35–54), a large fraction of CKD-related DALYs was linked to other and unspecified causes. In contrast, T2DM and hypertension predominated as CKD causes in older populations (55–74 and 75–95+ years) **(Figure 4d)**.

When stratified by Socio-demographic Index (SDI) quintiles, the 55–74 age group consistently showed the highest case counts across all quintiles, with the middle SDI quintile reporting the greatest numbers. Overall, higher prevalence was observed in the 35–54 and 55–74 groups within middle SDI levels, whereas low SDI quintiles recorded fewer cases. Mortality rates rose progressively with age, reaching their peak in the 75–95+ group. Examining mortality across SDI quintiles revealed an age-associated increase, with the 55–74 age group showing the largest death counts in medium, low-medium, and low SDI categories **(Figures 4e–4h).**

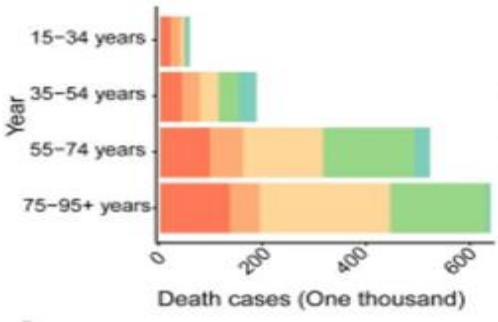
Gender-focused analysis **(Figures 4i–4p)** uncovered minimal variation across SDI quintiles. Globally and within SDI categories, females exhibited slightly elevated age-standardized incidence rates (ASIR) and prevalence rates (ASPR) compared to males. In contrast, males had higher age-standardized mortality rates (ASMR) and disability-adjusted life years rates (ASDR). The greatest ASIRs for both sexes were in the high SDI quintile, exceeding global averages. Males in middle and low-middle SDI quintiles showed ASPR above global levels, while females in low-middle and high-middle SDI quintiles had rates roughly matching global figures. Patterns for ASMR and ASDR followed suit, with highest values in low SDI quintiles; males in low-middle, middle, and high SDI groups had comparatively lower rates. Females in the high SDI quintile recorded the lowest ASMR and ASDR, with similar rates found in low-middle and middle SDI females. Results highlighted that males generally have higher ASIR and ASPR, whereas females exhibit greater ASMR and ASDR.



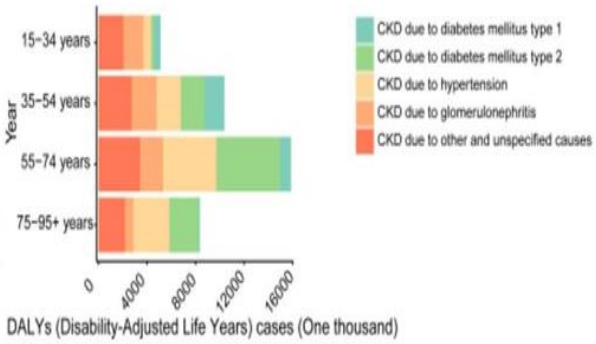
a)



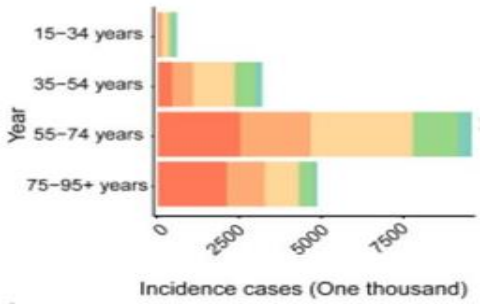
b)



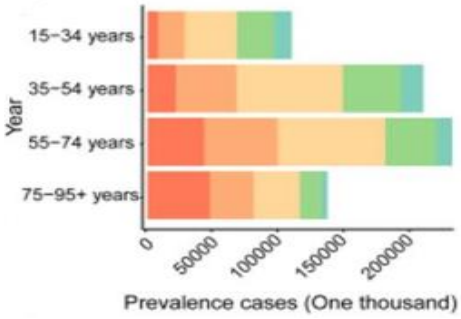
c)



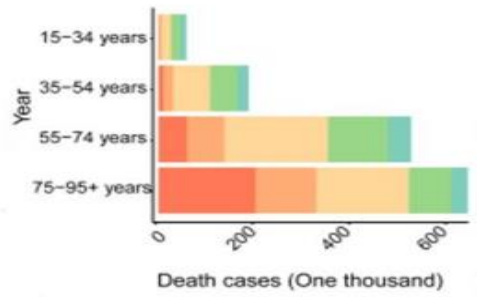
d)


15–34 years
35–54 years
55–74 years
75–95+ years
Year
0
2500
5000
7500
Incidence cases (One thousand)

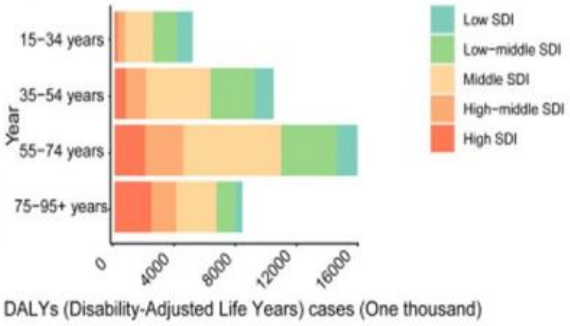
e)


15–34 years
35–54 years
55–74 years
75–95+ years
Year
0
50000
100000
150000
200000
Prevalence cases (One thousand)

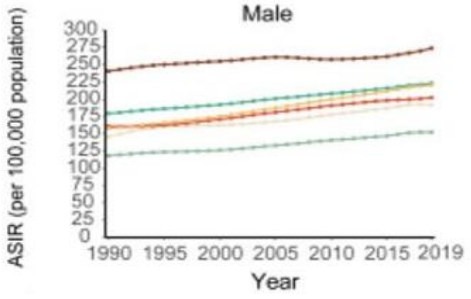
f)


15–34 years
35–54 years
55–74 years
75–95+ years
Year
0
200
400
600
Death cases (One thousand)

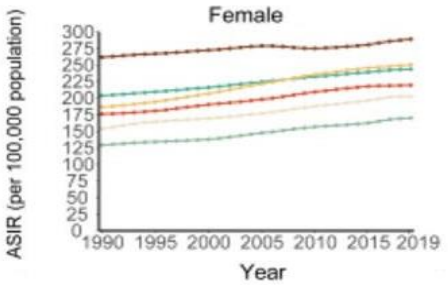
g)


15–34 years
35–54 years
55–74 years
75–95+ years
Year
0
4000
8000
12000
16000
DALYs (Disability-Adjusted Life Years) cases (One thousand)
Low SDI
Low-middle SDI
Middle SDI
High-middle SDI
High SDI

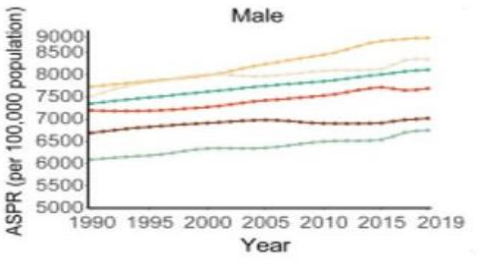
h)


Male
ASIR (per 100,000 population)
300
275
250
225
200
175
150
125
100
75
50
25
0
1990 1995 2000 2005 2010 2015 2019
Year

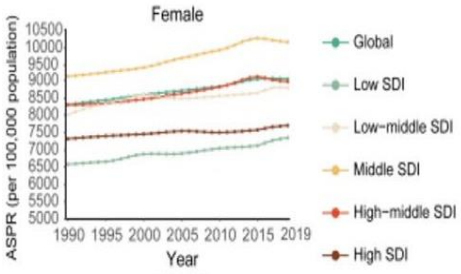
i)


Female
ASIR (per 100,000 population)
300
275
250
225
200
175
150
125
100
75
50
25
0
1990 1995 2000 2005 2010 2015 2019
Year

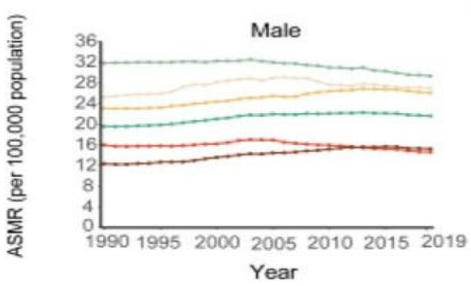
j)


Male
ASPR (per 100,000 population)
9000
8500
8000
7500
7000
6500
6000
5500
5000
1990 1995 2000 2005 2010 2015 2019
Year

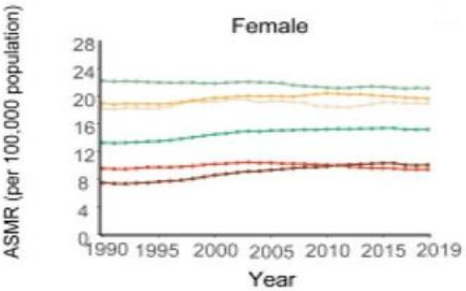
k)


Female
ASPR (per 100,000 population)
10500
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
1990 1995 2000 2005 2010 2015 2019
Year
Global
Low SDI
Low-middle SDI
Middle SDI
High-middle SDI
High SDI

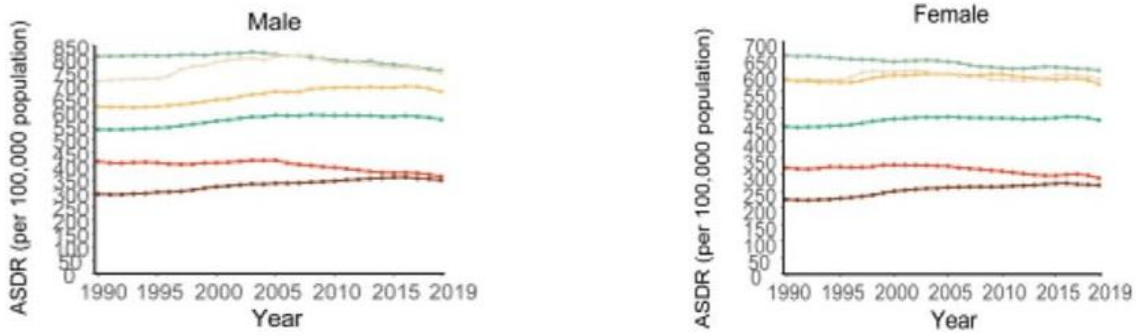
l)


Male
ASMR (per 100,000 population)
36
32
28
24
20
16
12
8
4
0
1990 1995 2000 2005 2010 2015 2019
Year

m)


Female
ASMR (per 100,000 population)
28
24
20
16
12
8
4
0
1990 1995 2000 2005 2010 2015 2019
Year

n)



o) p)

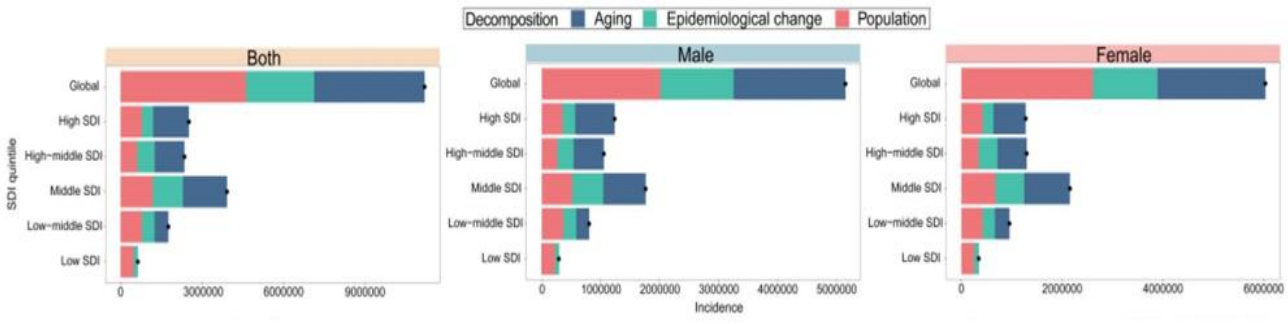
Figure 4. The incidence (a), prevalence (b), mortality (c), and disability-adjusted life years (DALYs) (d) associated with CKD resulting from various pathogenic factors across four age categories: 15–34, 35–54, 55–74, and 75–95+ years. The panels E to H depict the incidence (e), prevalence (f), mortality (g), and DALYs (h) of CKD distributed among five SDI quintiles: Low SDI, Low-middle SDI, Middle SDI, High-middle SDI, and High SDI. Additionally, age-standardized rates for incidence (ASIR), prevalence (ASPR), mortality (ASMR), and DALYs (ASDR) are calculated and presented according to region and gender in panels i through p.

Drivers of CKD epidemiology – ageing, population growth, and epidemiological change

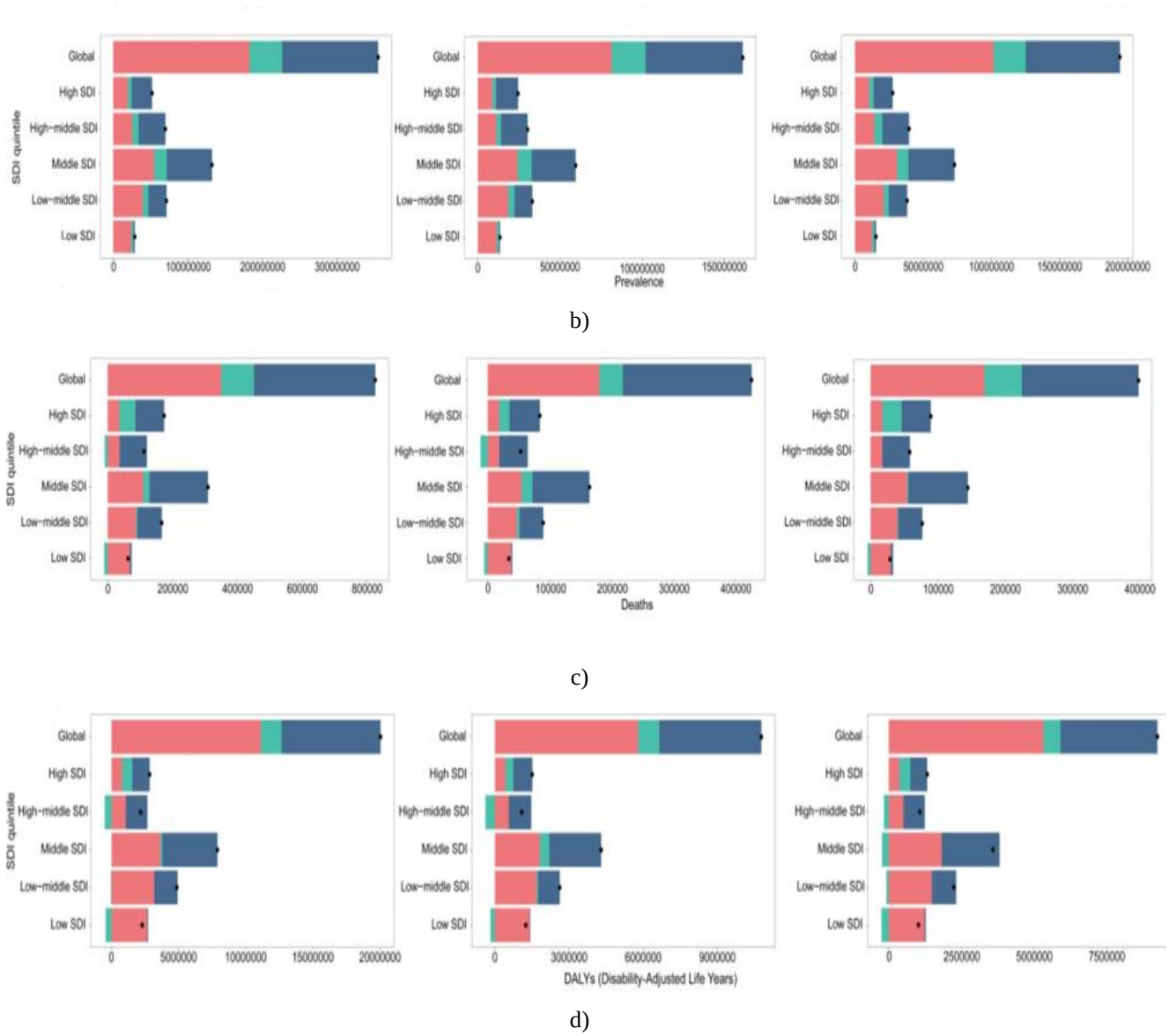
To assess how ageing, population growth, and epidemiological shifts influenced CKD epidemiology between 1990 and 2019, we performed a decomposition analysis on the raw data of incidence, prevalence, mortality, and DALYs. This analysis separated the contributions of ageing, epidemiologic changes (reflected by standardized morbidity and mortality rates), and population growth.

Worldwide, CKD incidence, prevalence, mortality, and DALYs have all been increasing, with ageing, epidemiologic changes, and population growth each playing significant roles. Regarding incidence rates, population growth was the primary driver, accounting for 41.31% of the increase, followed closely by ageing at 36.31%. Between 1990 and 2019, ageing had the greatest influence in High SDI regions, contributing 52.36% to the increase. This effect gradually lessened across high-middle, medium, and low-middle SDI regions, becoming almost negligible in low SDI regions (0.16 percent). The middle SDI region experienced a sharper rise in incidence rates compared to other SDI groups, with ageing responsible for 41.56 percent of this change. Conversely, incidence rates in low SDI regions showed minimal shifts, largely driven by population growth (75.19 percent) **(Figure 5a, Table 1)**.

At the global level, the rise in CKD prevalence was predominantly fueled by population growth (51.44 percent), while epidemiologic changes contributed modestly (12.33 percent). Among the SDI quintiles, the middle SDI group saw the most substantial increase. Similar to incidence trends, ageing had the strongest impact in the high SDI quintile (52.61 percent), decreasing in influence through lower SDI categories, with the least effect in the low SDI quintile (6.60 percent). Notably, unlike the ageing impact on incidence, the influence of ageing on prevalence showed an increasing trend from high to low SDI quintiles: 37.45 percent, 36.59 percent, 41.31 percent, 55.44 percent, and 83.43 percent, respectively. The contribution of epidemiologic changes to prevalence remained relatively stable across all five SDI quintiles, fluctuating between 9% and 13 percent **(Figure 5b; Table 1)**.



a)



b)

c)

d)

Figure 5. The global changes in CKD incidence (a), prevalence (b), mortality (c), and DALYs (d) from 1990 to 2019, analyzed according to aging, epidemiologic change, population growth, and SDI quintiles. The black dots indicate the overall combined contribution of all three factors. Positive values for each component signify an increase in CKD attributed to that factor, while negative values represent a decrease in CKD linked to the respective component.

Over the course of 30 years, CKD mortality was largely driven by aging (45.40 percent) and population growth (42.39 percent), whereas epidemiologic changes played a comparatively minor role (12.21%). The middle SDI quintile showed the greatest rise in CKD mortality. The effect of epidemiologic changes on mortality declined in both the high-middle and low SDI quintiles. Within the high-middle SDI quintile, aging was the dominant factor, accounting for 75.84% of the increase in CKD mortality—significantly more than in the other SDI quintiles. In contrast, the low SDI quintile experienced only a minimal impact from aging (8.45%), but population growth had a notably strong effect (108.60 percent) **(Figure 5c; Table 1)**.

Regarding the global DALYs rate of CKD, population growth was the main contributor (55.52%), followed by aging (36.82%), while epidemiologic changes had the smallest influence (7.66%). The influence of epidemiologic changes on DALYs rates decreased notably within the high-middle, low-middle, and low SDI quintiles. Similar to mortality patterns, the middle SDI quintile witnessed the most significant rise in DALYs rates. Aging markedly affected the high-middle SDI group (74.57%) but had little effect on the low SDI quintile (3.04 percent). Population growth's impact was greatest in the low SDI quintile (116.35 percent) and least in the high SDI quintile (27.91 percent) **(Figure 5d; Table 1)**.

HAQ and SDI

To explore the relationship between Healthcare Access and Quality (HAQ) and CKD burden, we analyzed correlations between age-standardized rates and HAQ.

The results indicated that countries with moderate HAQ levels exhibited elevated ASIR and ASPR. In contrast, nations with low HAQ showed higher ASMR and ASDR, while those with high HAQ experienced reduced ASMR and ASDR. Overall, countries with limited healthcare capacity bear a disproportionately high CKD burden **(Figure 6)**.

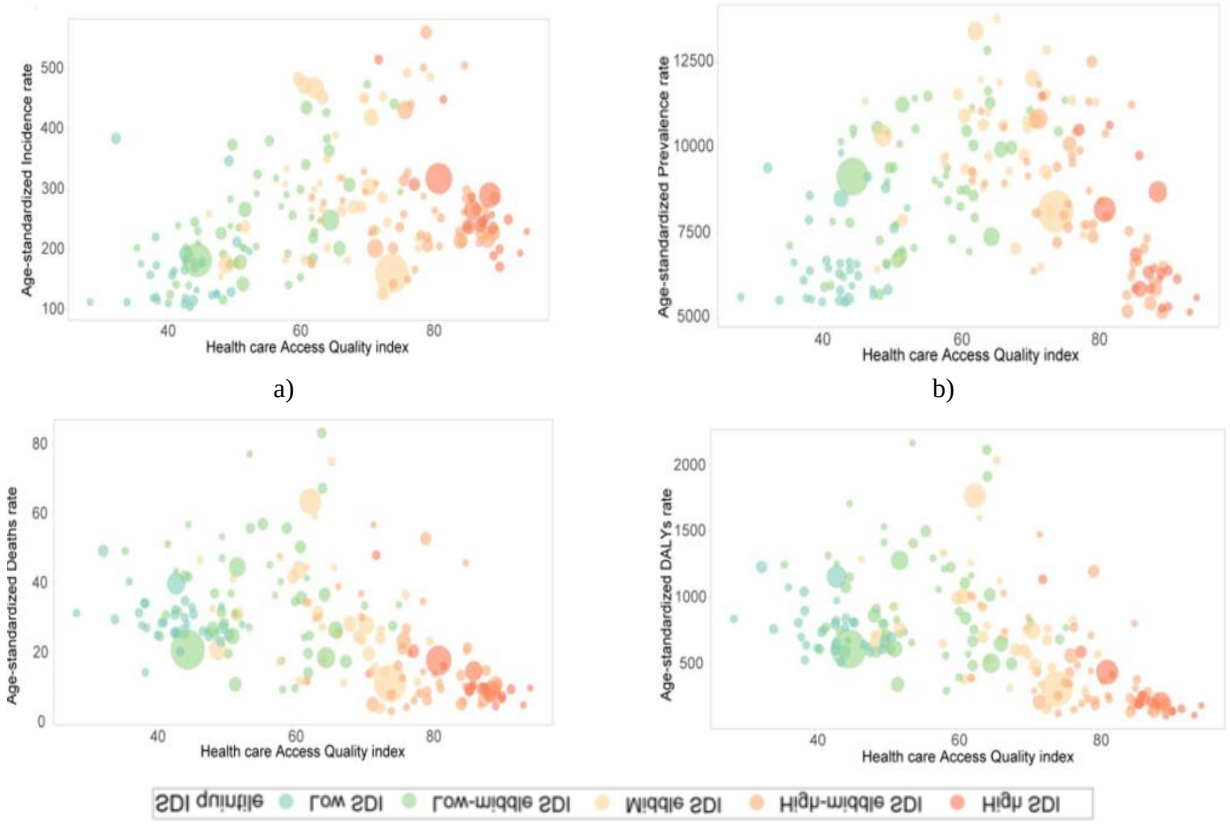


Figure 6. Relationship between age-standardized incidence (a), prevalence (b), mortality (c), and DALYs (d) rates and the HAQ index. Each circle denotes a specific country, with color indicating its corresponding SDI quintile. The size of each circle reflects the population size.

Across both global and GBD regional levels from 1990 to 2019, notable variations were identified in how age-standardized rates correlated with the SDI. A positive association emerged between ASIR and SDI, whereas ASMR and ASDR were inversely related to SDI. The connection between ASPR and SDI was relatively weak **(Figure 6b)**. When analyzing the ASIR-SDI correlation, the median SDI deviated significantly from predicted values. At the global level, regions such as North Africa, the Middle East, and Central Latin America reported ASIR values that exceeded expectations, in contrast to Central and East Asia and Eastern Europe, where values fell below projected levels **(Figure 6a)**. Trends in the relationship between ASMR and ASDR with SDI followed a similar pattern, although regional differences were substantial **(Figures 6c and 6d)**. In particular, some areas within the Low and low-middle SDI groups demonstrated a downward trajectory in correlation, while other low-middle SDI regions trended upward. Middle SDI areas experienced a marked decline, whereas both high-middle and high SDI regions showed increasing trends. Regions including South Asia, Oceania, Andean Latin America, Central Latin America, Sub-Saharan Africa, the Caribbean, Central Asia, Southern Latin America, and high-income North America had a positive association with SDI, while other regions showed either a neutral or negative link. The regional and national correlations between SDI and age-standardized rates are visualized in **Figure 7**, where ASIR and ASPR show positive associations with SDI, and ASMR and ASDR demonstrate negative associations.

CKD burden attributed to each risk factor by SDI

As depicted in **Figure 8**, high fasting plasma glucose and high systolic blood pressure remain the predominant causes of CKD-related mortality. The population attributable fraction (PAF) decreases more steeply from high to low SDI regions. While factors such as high BMI, poor diet, and insufficient physical activity play a more dominant role in higher SDI regions, environmental exposures tend to contribute more significantly in lower SDI settings.

Over the last three decades, high systolic blood pressure has exhibited a downward trajectory in high SDI areas **(Figure 9)**, but it has simultaneously increased in regions with lower SDI levels. Despite the decline in high SDI settings, hypertension continues to be a major driver of CKD-related deaths. Moreover, aside from high systolic blood pressure, the PAF for all other contributing factors has steadily increased over the past thirty years.

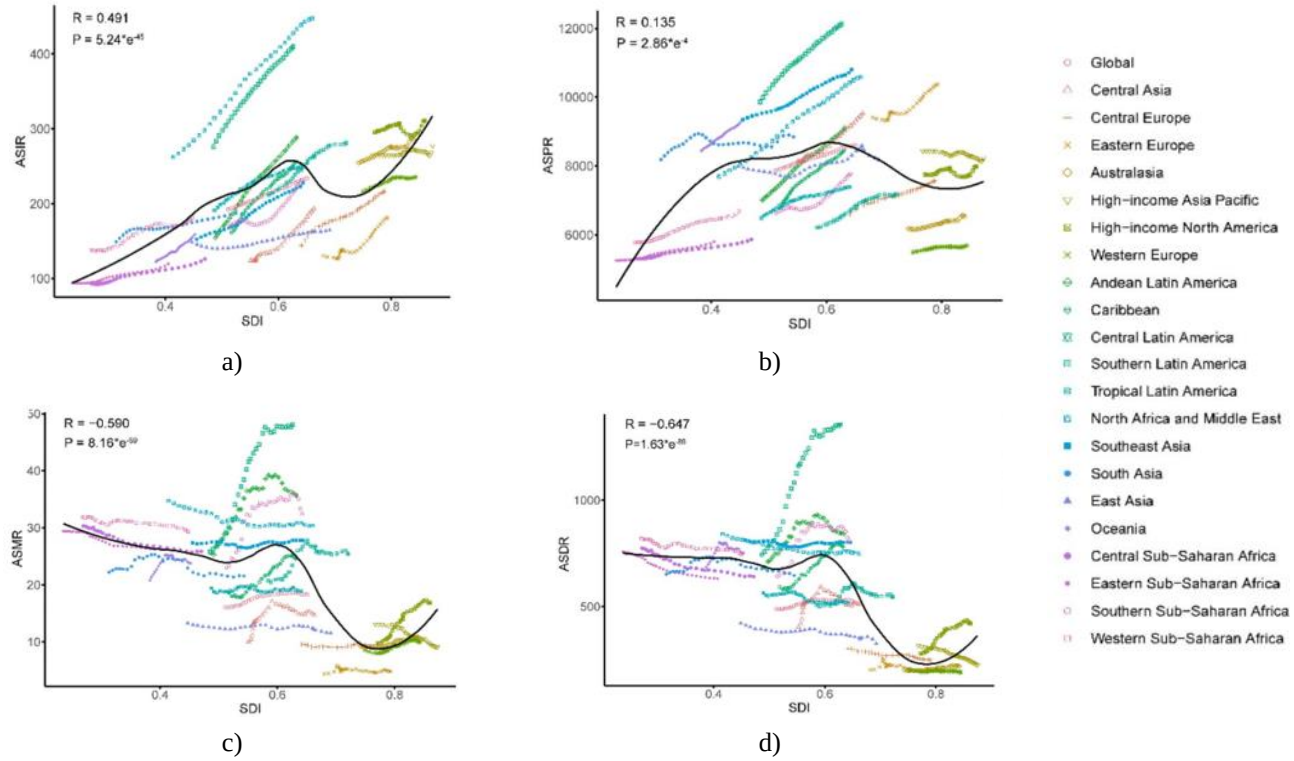


Figure 7. Age-standardized incidence rates (a), age-standardized prevalence rates (b), age-standardized mortality rates (c), and age-standardized disability-adjusted life years rates (d) related to CKD across 21 GBD regions, categorized by Socio-demographic Index, during the period from 1990 to 2019.

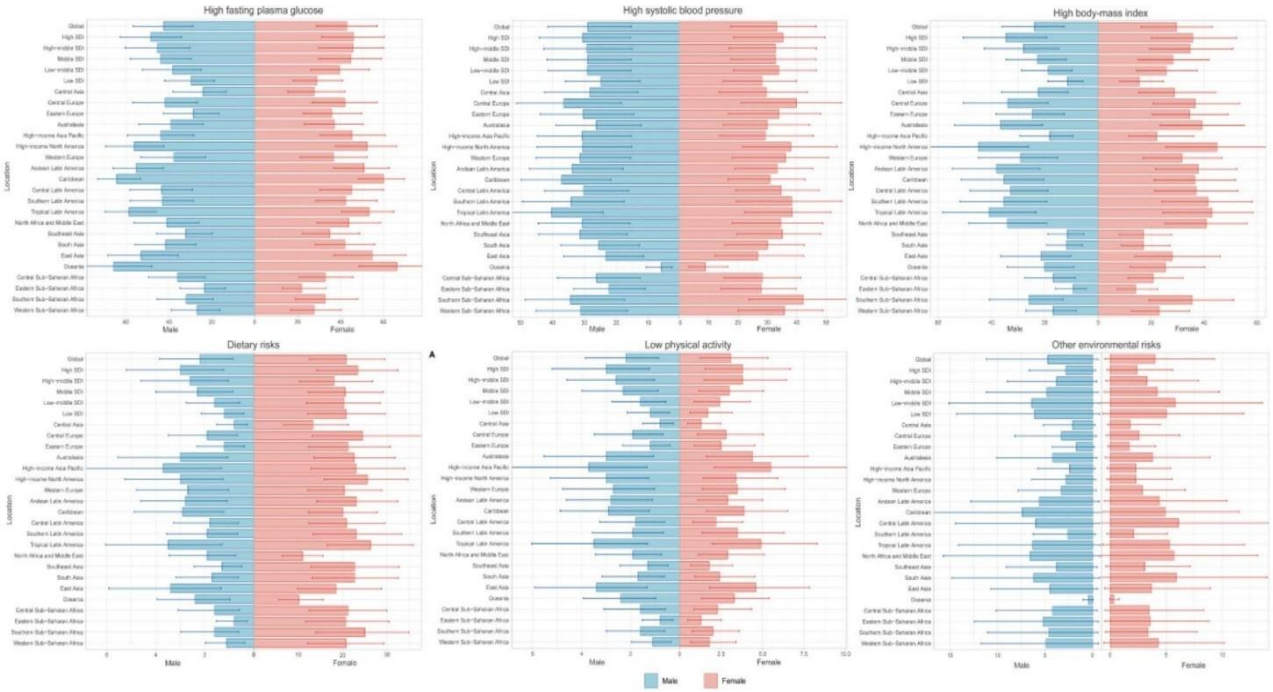


Figure 8. The PAF of these six risk factors for CKD deaths in 2019

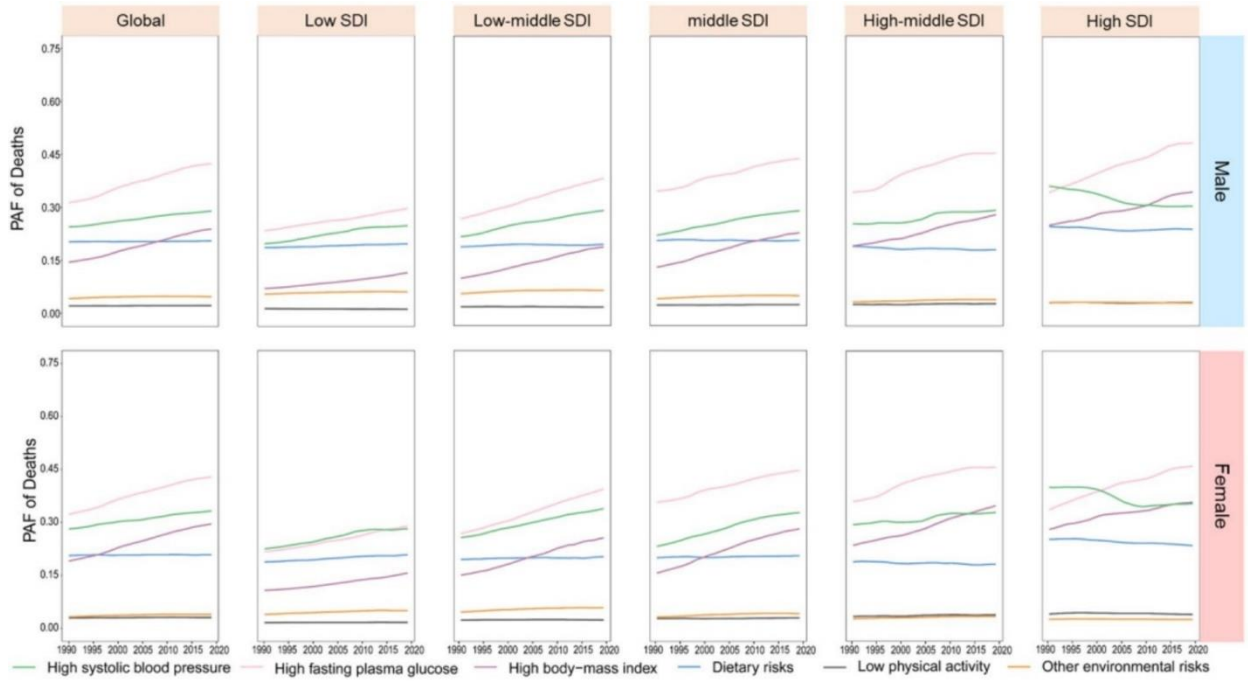


Figure 9. Contributions of 6 risk factors to the PAF of deaths due to CKD by different SDI quintiles and sex from 1990 to 2019

This study offers a comprehensive evaluation of the global burden of chronic kidney disease (CKD) by examining age- and sex-specific patterns in incidence, prevalence, mortality, and disability-adjusted life years (DALYs) among adults aged 20 to over 95 years. Our findings reveal substantial increases across all four indicators over the past 30 years, indicating a rising global impact of CKD. By 2019, the number of new CKD cases had surged by 144% compared to 1990, affecting nearly 19 million individuals. The global prevalence rose by 104%, with more than 697 million people living with CKD. Mortality due to CKD also saw a steep climb, increasing by 137% and accounting for around 1.4 million deaths. Furthermore, over 41 million healthy years were lost to CKD in 2019, reflecting a 93% rise in DALYs since 1990.

Our decomposition analysis identified demographic shifts—particularly population growth and aging—as the primary drivers of the increasing CKD burden, while epidemiological transitions played a smaller role. Countries in the middle Socio-demographic Index (SDI) quintiles consistently experienced the heaviest burden in terms of incidence, prevalence, mortality, and DALYs, likely due to their larger populations and greater susceptibility to the effects of aging and demographic expansion.

CKD was the 18th leading cause of death globally in 1990 but rose to 11th place by 2019 [37]. While there has been an overall decrease in CKD incidence and mortality since 2016 across most etiologies, age-standardized mortality rates (ASMR) linked to glomerulonephritis have increased, suggesting that improvements in CKD outcomes have not been uniform. Enhanced strategies for managing glomerulonephritis are therefore necessary. Additionally, although females exhibited higher CKD incidence and prevalence, males had greater mortality and DALYs, which may indicate a faster progression to end-stage renal disease (ESRD) among men. This sex-based disparity could stem from unhealthier behaviors in males and the possible protective effects of estrogen or harmful influence of testosterone.

From 1990 to 2019, the total global DALYs for all diseases showed a slight decline, dropping from 2.59 billion (95% CI = 2.31–2.44 billion) to 2.53 billion (95% CI = 2.29–2.81 billion). Likewise, the age-standardized DALY rate (ASDR) fell considerably from 50,059.93 to 32,856.98 per 100,000 population, indicating an overall improvement in global health. However, DALYs attributable to CKD rose markedly—from 21.5 million to 41.5 million—and the ASDR for CKD increased from 484.46 to 514.86. This escalation places CKD as the twelfth most significant risk factor worldwide, highlighting its growing contribution to global disease burden. At the same time, there is a notable epidemiological transition underway, with the global disease profile shifting from communicable to non-communicable diseases. CKD's share of the non-communicable disease burden has grown from 1.9% to 2.6%, underscoring its increasingly critical role in shaping global health outcomes [38].

The influence of hypertension on chronic kidney disease (CKD) primarily emerges through its detrimental impact on target organs and its contribution to adverse cardiovascular outcomes. This effect is closely linked to the correlation between reduced estimated glomerular

filtration rate (eGFR) and albuminuria with heightened cardiovascular mortality risk [10]. Over the past three decades, the population attributable fraction (PAF) has increased in most regions, excluding those with high Socio-Demographic Index (SDI). This trend may be due to high SDI areas benefiting from better funding and more robust educational infrastructure, which improve patient awareness and facilitate early diagnosis and effective treatment strategies. As outlined in the 2021 KDIGO Clinical Practice Guideline for the Management of Blood Pressure in Chronic Kidney Disease, maintaining a systolic blood pressure below 120 mmHg is advised for optimal clinical outcomes. However, in low SDI areas such as Africa, research shows that only 51.4% of individuals with hypertension were aware of their condition, and just 51.8% had taken antihypertensive medication in the preceding two weeks [39]. These findings highlight the ongoing need for national-level initiatives to improve hypertension management in such regions.

Both hypertension and hyperglycemia are recognized as key contributors to diabetes, with diabetic kidney disease being a leading cause of CKD globally [40]. In the last 30 years, hyperglycemia has demonstrated a rising trend across all regions, emerging as the top contributing risk factor for CKD-related mortality. This pattern underscores the widespread inadequacy in glycemic control, irrespective of a region's economic standing, and signifies a major obstacle in CKD management. For diabetic patients with CKD not undergoing dialysis, a personalized HbA1c target between <6.5% and <8.0% is recommended, alongside adopting a low-sodium diet and engaging in moderate-intensity physical activity [41].

Current evidence suggests that diet-related risk factors for CKD are predominantly linked to protein intake. Diets high in protein have been associated with elevated urinary albumin levels and an initial increase in GFR, which may eventually decline. Furthermore, such diets are increasingly connected to metabolic disturbances that can negatively affect renal function [42]. Although the PAF associated with dietary risks has remained relatively constant over the past three decades, it still accounts for a considerable portion of CKD mortality. The 2024 KDIGO guidelines advocate for a whole-food, plant-based diet that minimizes consumption of animal-derived and ultra-processed foods to help slow CKD progression and address related cardiovascular issues such as hypertension and diabetes [43].

High body mass index (BMI) and insufficient physical activity are key contributors to obesity, and the link between obesity and chronic kidney disease (CKD) has gained growing attention in recent years. A Lancet article analyzed obesity's global health impact, observing that wealthier nations carry a heavier obesity burden than low- and middle-income countries. Countries undergoing economic transitions from low to high income have experienced rapid urbanization and a shift toward motorized transportation, leading to reduced physical activity and a rise in obesity rates [44]. This corresponds with our findings showing that as the Socio-Demographic Index (SDI) decreases, the population attributable fraction (PAF) related to BMI and low physical activity also diminishes, emphasizing the substantial influence of these factors in high-income areas. Addressing these challenges requires a coordinated global effort to establish appropriate strategies and improve governance standards. Additionally, high SDI regions must refine policies and strengthen urban governance to promote meaningful transformation.

Growing evidence points to environmental air pollution—specifically particulate matter (PM), nitrogen dioxide (NO2), and nitrogen oxides (NO)—as significant risk factors for hypertension, diabetes, and CKD development [45, 46]. The PAF linked to environmental pollution tends to decline with rising SDI, likely because wealthier countries generally enjoy better economic conditions, lower pollution levels, and more effective environmental protections. Research using UK Biobank data revealed that PM2.5, PM10, NO2, and NOx exposure is associated with increased risks of progressing from a healthy state to newly diagnosed hypertension, diabetes, and CKD [46]. Despite this, current clinical guidelines do not include environmental pollution prevention measures. Based on our findings, we strongly recommend integrating pollution control into primary prevention strategies for CKD and urge relevant authorities to enact corresponding laws and regulations.

The burden of CKD exhibits clear regional and developmental variations. Regarding the SDI, age-standardized mortality rates (ASMR) and age-standardized disability rates (ASDR) are comparatively lower in high and high-middle SDI countries than in the other three SDI categories, with the high-middle SDI group showing relatively stable estimated annual percentage changes (EAPC) in ASMR and ASDR. Analyzing data from 204 countries indicates that the United States, Germany, Canada, the United Kingdom, Turkey, Iran, and Japan all report high age-standardized incidence rates (ASIR) coupled with low ASDR, suggesting that effective CKD management correlates with a nation's level of economic development. Our results highlight a concentration of CKD incidence and prevalence in North Africa and the Middle East, regions that demonstrate higher rates compared to others. This disparity may be due to widespread unhealthy dietary patterns and lifestyles prevalent in these populations, which likely contribute to increased CKD rates and underline the necessity for focused health interventions

targeting modifiable risk factors [47]. Furthermore, studies have linked non-communicable diseases to education levels, which tend to be relatively low in this area, affecting disease awareness. Healthcare services are somewhat limited, and there is a lack of timely adjustments in public health policies [48].

The overall age-standardized mortality rate (ASMR) and age-standardized disability rate (ASDR) for chronic kidney disease (CKD) are significantly elevated in Africa, with certain countries in Asia, North America, and South America also showing high levels. In contrast, Europe exhibits the lowest rates. Additionally, there are noticeable differences in age-standardized incidence rate (ASIR), age-standardized prevalence rate (ASPR), ASMR, and ASDR for CKD across various countries worldwide. Notably, Sub-Saharan Africa experiences relatively lower ASIR and ASPR but higher ASMR and ASDR, emphasizing the crucial importance of renal replacement therapy in this region. Evidence indicates that access to renal replacement therapy in both high-income and low-income regions is approximately 200 times greater than in Sub-Saharan Africa. Research from Sub-Saharan Africa reveals that only 10% of adults with newly diagnosed renal failure requiring dialysis are able to sustain dialysis treatment for three months or more, and merely 1% continue for 12 months or longer. Moreover, it is estimated that 96% of adults known or presumed to have died did so due to the inability to afford medical costs [49]. This stark disparity highlights the urgent necessity to improve access to renal healthcare services and interventions in the most affected regions to reduce the CKD burden and enhance patient outcomes [50]. As a result, many patients in these areas are either unable to start treatment because of high costs or are forced to stop treatment prematurely, which severely reduces life expectancy. An analysis combining age-standardized rates with the Socio-Demographic Index (SDI) and Healthcare Access and Quality (HAQ) index further demonstrates this issue. Generally, lower SDI quintiles and HAQ scores correspond with reduced ASIR and ASPR but increased ASMR and ASDR for CKD. This trend highlights that the CKD burden is disproportionately concentrated in economically disadvantaged regions, underscoring the urgent need to improve healthcare access and affordability to lessen CKD's impact in these areas.

This study has several limitations worth noting. Firstly, our research centers on a broad evaluation of global, regional, and national epidemiological trends of chronic kidney disease (CKD) in adults, excluding pediatric cases. This focus limits the ability to present a complete picture of the disease's full spectrum. Secondly, although the Global Burden of Disease (GBD) database offers detailed statistics, data scarcity in certain countries or regions may introduce bias into the analyses. Thirdly, we did not conduct a detailed country-specific examination, so caution is advised when applying these results to nations with low Healthcare Access and Quality (HAQ) scores. Additionally, the decomposition analysis method poses difficulties in distinctly separating the effects of population aging from changes in population size. Importantly, information regarding diabetes-induced nephropathy is primarily derived from the Geisinger Health System in Pennsylvania, USA, and has been generalized to other countries, which may affect its applicability.

Nonetheless, this study has significant strengths. It utilizes the extensive 1990–2019 GBD database, currently the most comprehensive source of global health data. Moreover, by applying multiple modeling approaches and decomposition analyses, the study facilitates comparisons across countries and regions, thereby deepening the understanding of CKD epidemiology in diverse settings.

In conclusion, our epidemiological evaluation provides important insights for CKD management. Since the burden of CKD is predominantly found in economically disadvantaged areas, a recent assessment of kidney care capacity across countries found that only 21 (18 percent) and 9 (8 percent) countries consistently have serum creatinine, estimated glomerular filtration rate (eGFR), and proteinuria testing available for CKD monitoring within primary healthcare. Furthermore, public funding and free access to hemodialysis, peritoneal dialysis, and transplant services exist in only 50 (42 percent), 48 (51 percent), and 46 (49 percent) countries, respectively [51]. Thus, improving CKD monitoring and patient care infrastructure can substantially enhance disease management. Given the scarcity of dialysis and transplant options in low-income nations, early interventions aimed at symptom control may help delay CKD progression.

Conclusion

Since 1990, there has been a notable rise in the incidence, prevalence, mortality, and disability-adjusted life years (DALYs) attributable to chronic kidney disease (CKD). This increase is mainly driven by demographic factors such as population growth and aging. Gender and age disparities were also observed, with females experiencing higher age-standardized incidence rates (ASIR) and prevalence rates (ASPR), while males showed elevated age-standardized mortality rates (ASMR) and age-standardized disability-adjusted life years rates (ASDR). The uneven distribution of CKD burden, particularly in regions with lower economic development and weaker health systems, highlights an urgent requirement for targeted public health policies to reduce global inequities in CKD outcomes.

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References

1. Levey AS, Jong PEd, Coresh J, Nahas ME, Matsushita BCA, Gansevoort RT, et al. The definition, classification, and prognosis ofchronic kidney disease: a KDlGO Controversies Conference report. Kidney International; 2011.
2. KDIGO. 2024 clinical practice guideline for the evaluation and management of chronic kidney disease. Kidney Int. 2024;105(4s):S117-s314.
3. Hojs R, Ekart R, Bevc S, Vodošek Hojs N. Chronic kidney disease and obesity. Nephron. 2023;147(11):660–4.
4. Ruiz-Ortega M, Rayego-Mateos S, Lamas S, Ortiz A, Rodrigues-Diez RR. Targeting the progression of chronic kidney disease. Nat Rev Nephrol. 2020;16(5):269–88.
5. Drawz P, Rahman M. Chronic kidney disease. Ann Intern Med. 2015;162(11):ITC1–16.
6. Bikbov B, Purcell CA, Levey AS, Smith M, Abdoli A, Abebe M, et al. Global, regional, and national burden of chronic kidney disease, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet. 2020;395(10225):709–33.
7. Glassock RJ, Warnock DG, Delanaye P. The global burden of chronic kidney disease: estimates, variability and pitfalls. Nat Rev Nephrol. 2016;13(2):104–14.
8. Thomas MC, Brownlee M, Susztak K, Sharma K, Jandeleit-Dahm KAM, Zoungas S, et al. Diabetic kidney disease. Nat Rev Dis Primers. 2015;1(1):1-20.
9. Gupta S, Dominguez M, Golestaneh L. Diabetic kidney disease. Med Clin North Am. 2023;107(4):689–705.
10. Burnier M, Damianaki A. Hypertension as cardiovascular risk factor in chronic kidney disease. Circul Res. 2023;132(8):1050–63.
11. Pugh D, Gallacher PJ, Dhaun N. Management of hypertension in chronic kidney disease. Drugs. 2019;79(4):365–79.
12. Chen TK, Knicely DH, Grams ME. Chronic kidney disease diagnosis and management: a review. JAMA. 2019;322(13):1294–304.
13. Xie Y, Bowe B, Mokdad AH, Xian H, Yan Y, Li T, et al. Analysis of the global burden of disease study highlights the global, regional, and national trends of chronic kidney disease epidemiology from 1990 to 2016. Kidney Int. 2018;94(3):567–81.
14. Global regional, national burden of chronic kidney disease. 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet (London England). 2020;395(10225):709–33.
15. Deng Y, Li N, Wu Y, Wang M, Yang S, Zheng Y, et al. Global, regional, and national burden of diabetes-related chronic kidney disease from 1990 to 2019. Front Endocrinol (Lausanne). 2021;12:672350.
16. Li Y, Ning Y, Shen B, Shi Y, Song N, Fang Y, et al. Temporal trends in prevalence and mortality for chronic kidney disease in China from 1990 to 2019: an analysis of the Global Burden of Disease Study 2019. Clin Kidney J. 2023;16(2):312–21.
17. Zhang J, Ma B, Han X, Ding S, Li Y. Global, regional, and national burdens of HIV and other sexually transmitted infections in adolescents and young adults aged 10–24 years from 1990 to 2019: a trend analysis based on the Global Burden of Disease Study 2019. Lancet Child Adolesc Health. 2022;6(11):763–76.
18. Stevens GA, Alkema L, Black RE, Boerma JT, Collins GS, Ezzati M, et al. Guidelines for accurate and transparent health estimates reporting: the GATHER statement. Lancet. 2016;388(10062):e19–23.
19. Qian Z, Li Y, Guan Z, Guo P, Zheng K, Du Y, et al. Global, regional, and national burden of multiple sclerosis from 1990 to 2019: findings of global burden of disease study 2019. Front Public Health. 2023;11:1073278.
20. Su Z, Zou Z, Hay SI, Liu Y, Li S, Chen H, et al. Global, regional, and national time trends in mortality for congenital heart disease, 1990–2019: An age-period-cohort analysis for the Global Burden of Disease 2019 study. eClinicalMedicine. 2022;43.
21. Wu CC, Hwang SJ, Hsu CC, Lu KC. Challenges of measuring the healthcare access and quality index. Lancet. 2018;391(10119):428–9.
22. Jagannathan R, Patel SA, Ali MK, Narayan KMV. Global updates on cardiovascular disease mortality

trends and attribution of traditional risk factors. Curr Diab Rep. 2019;19(7):44.
23. Hu J, Dong H, Dong Y, Zhou R, Teixeira W, He X, et al. Cancer burden attributable to risk factors, 1990–2019: a comparative risk assessment. iScience. 2024;27(4):109430.
24. Global. burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the global burden of disease study 2019. Lancet (London, England) 2020;396(10258):1223–49.
25. Global regional. national burden of stroke and its risk factors, 1990–2019: a systematic analysis for the global burden of disease study 2019. Lancet Neurol. 2021;20(10):795–820.
26. Yang Q, Xu D, Yang Y, Lu S, Wang D, Wang L. Global, regional, and national burden of gastric cancer in adolescents and young adults, 1990–2019: a systematic analysis for the global burden of disease study 2019. Am J Gastroenterol. 2024;119(3):454–67.
27. Liu Q, He H, Yang J, Feng X, Zhao F, Lyu J. Changes in the global burden of depression from 1990 to 2017: findings from the Global Burden of Disease study. J Psychiatr Res. 2020;126:134–40.
28. Cheng F, Xiao J, Shao C, Huang F, Wang L, Ju Y, et al. Burden of Thyroid cancer from 1990 to 2019 and projections of incidence and mortality until 2039 in China: findings from global burden of disease study. Front Endocrinol. 2021;12:738213.
29. Hu J, Zhou R, Ding R, Ye DW, Su Y. Effect of PM2.5 air pollution on the global burden of lower respiratory infections, 1990–2019: a systematic analysis from the global burden of disease study 2019. J Hazard Mater. 2023;459:132215.
30. Liu X, Zhang J, Wang S. Global, regional, and national burden of infertility attributable to PCOS, 1990–2019. Hum Reprod. 2024;39(1):108–18.
31. Qin X, He J, He H, Yuan X, Su X, Zeng X. Long-term trends in the burden of edentulism in China over three decades: A Joinpoint regression and age-period-cohort analysis based on the global burden of disease study 2019. Front Public Health. 2023;11:1099194.
32. Qiu H, Cao S, Xu R. Cancer incidence, mortality, and burden in China: a time- trend analysis and comparison with the United States and United Kingdom based on the global epidemiological data released in 2020. Cancer Commun. 2021;41(10):1037–48.
33. Zhang ZM, Lin ZL, He BX, Yan WT, Zhang XY, Zhang ZH, et al. Epidemiological analysis reveals a surge in inflammatory bowel disease among children and adolescents: a global, regional, and national perspective from 1990 to 2019 – insights from the China study. J Global Health. 2023;13:04174.
34. Gupta P. Standardization and decomposition of rates: a users's manual. US bureau census. Curr Popul Rep. 1993:123–86.
35. Gupta P. Standardization and decomposition of rates from cross-classified data. Genus. 1994;50:171–96.
36. Chevan A, Sutherland M. Revisiting das Gupta: refinement and extension of standardization and decomposition. Demography. 2009;46:429–49.
37. Levey AS, Grams ME, Inker LA. Uses of GFR and albuminuria level in acute and chronic kidney disease. N Engl J Med. 2022;386(22):2120–8.
38. Emadi M, Delavari S, Bayati M. Global socioeconomic inequality in the burden of communicable and non-communicable diseases and injuries: an analysis on global burden of disease study 2019. BMC Public Health. 2021;21(1):1771.
39. Parati G, Lackland DT, Campbell NRC, Owolabi MO, Bavuma C, MB H, et al. How to improve awareness, treatment, and control of hypertension in Africa, and how to reduce its consequences: a call to action from the world hypertension league. Hypertens (Dallas Tex: 1979). 2022;79(9):1949–61.
40. Alicic RZ, Rooney MT, Tuttle KR. Diabetic kidney disease: challenges, progress, and possibilities. Clin J Am Soc Nephrol. 2017;12(12):2032–45.
41. KDIGO. 2022 clinical practice guideline for diabetes management in chronic kidney disease. Kidney Int. 2022, 102(5s):S1-s127.
42. Ko GJ, Rhee CM, Kalantar-Zadeh K, Joshi S. The effects of high-protein diets on kidney health and longevity. J Am Soc Nephrol. 2020;31(8):1667–79.
43. Molina P, Gavela E, Vizcaíno B, Huarte E, Carrero JJ. Optimizing Diet to Slow CKD Progression. Front Med. 2021;8:654250.
44. Swinburn BA, Kraak VI, Allender S, Atkins VJ, Baker PI, Bogard JR, et al. The global syndemic of obesity, undernutrition, and climate change: the lancet commission report. Lancet (London England). 2019;393(10173):791–846.
45. Bowe B, Xie Y, Li T, Yan Y, Xian H, Al-Aly Z. The 2016 global and national bur- den of diabetes mellitus attributable to PM(2•5) air pollution. Lancet Planet Health. 2018;2(7):e301–12.
46. Wu G, Cai M, Wang C, Zou H, Wang X, Hua J, et al. Ambient air pollution and incidence, progression to multimorbidity and death of hypertension, diabetes, and chronic kidney disease: a national prospective cohort. Sci Total Environ. 2023;881:163406.
47. Park S, Lee S, Kim Y, Lee Y, Kang MW, Kim K, et al. Causal effects of physical activity or sedentary behaviors on kidney function: an integrated population-scale observational analysis and

Mendelian randomization study. Nephrol Dial Transplant. 2022;37(6):1059-68.

48. Rawshani A, Svensson AM, Zethelius B, Eliasson B, Rosengren A, Gudbjörnsdottir S. Association Between socioeconomic status and mortality, cardiovascular disease, and cancer in patients with type 2 diabetes. JAMA Intern Med. 2016;176(8):1146–54.
49. 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 Global health. 2017;5(4):e408–17.
50. Jadoul M, Aoun M, Imani MM. The major global burden of chronic kidney disease. Lancet Glob Health. 2024;12(3):e342-3.
51. Bello AK, Levin A, Tonelli M, Okpechi IG, Feehally J, Harris D, et al. Assessment of global kidney health care status. JAMA. 2017;317(18):1864–81.